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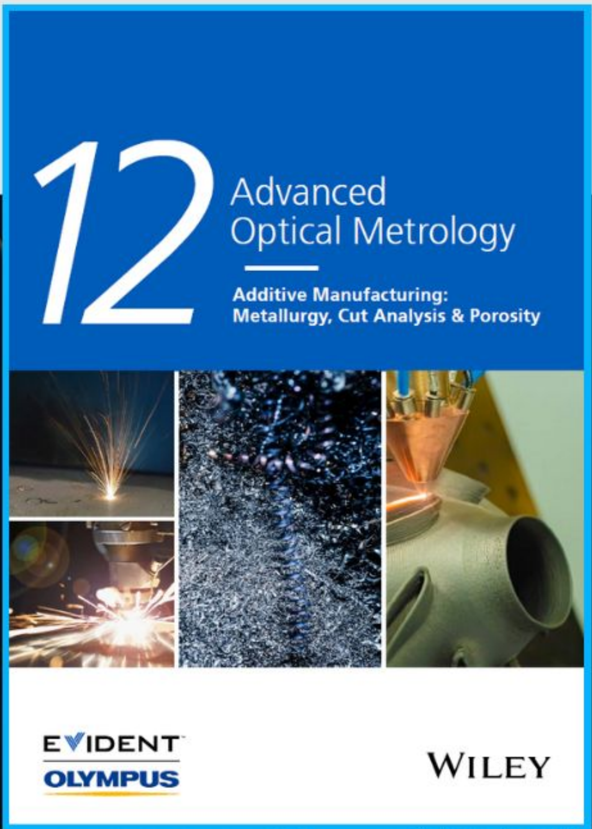

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Conceptual model for capability planning in a military context – A systems thinking approach

Jouni Koivisto[1,2] | **Risto Ritala**[2] | **Matti Vilkko**[2]

[1]Finnish Defence Research Agency, Riihimäki, Finland

[2]Automation Technology and Mechanical Engineering, Tampere University, Tampere, Finland

Correspondence
Jouni Koivisto, Finnish Defence Research Agency, FI-11311 Riihimäki, Finland.
Email: jouni.koivisto@mil.fi

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Abstract

During recent decades, planning defense systems have evolved into capability-based planning (CBP) processes. This paper seeks to answer two questions: firstly, how to express a complex, real-world capability requirement; and secondly, how to assess if a system with interacting elements fulfills this requirement. We propose that both a capability need and the solution fulfilling it are expressed with a consistent set of models in a traceable manner. The models integrate current capability models, specific to planning level and capability viewpoint, with systems thinking approach. Our conceptual model defines the defense system in its environment, our data model defines and organizes the CBP terms, and our class diagram defines the CBP planning elements. We illustrate the approach by giving an example of capability parametrization and compare it both with the DODAF capability view and with the generic CBP process. Our data model describes how capabilities are degraded in action and extends the approach toward capability dynamics. The quantitative capability definition aims to support efforts to solve for real world interacting subsystems that combined implement the required capability.

KEYWORDS
capability-based planning, capability model, systems thinking

1 | INTRODUCTION

Capability as a defense planning paradigm and capability-based planning (CBP) have evolved since the Cold War. The North Atlantic Treaty Organization (NATO)[1] and US Department of Defense (DoD)[2] consider a capability-based approach as a necessity to be able to undertake an evolving variety of operations, such as peacekeeping or peace enforcement operations, non-nation threats, and asymmetric warfare after the Cold War threat-based approach. In CBP, the capabilities are based on the manner in which future opponents may operate rather than based on certain opponents, allies, or geographical locations. Furthermore, CBP assesses solutions that fulfill a particular capability need.[3,4] This approach improves the prospect of finding more cost-effective ways to produce a capability rather than to rely on conventional and often obvious solutions. The CBP approach has been widely applied in NATO countries, but the practice of its application varies.[4] The US DoD Joint Capabilities Integration and Development System (JCIDS),[5] the Finnish Defence Forces Strategic Planning,[6] and the NATO Defence Planning Process (NDPP)[1] are examples of CBP processes. Common to all CBP approaches is that they distinguish between the military force design as required military effects and the solution for the implementation as military forces, systems, etc.

Not only is the CBP process applied differently but also the definition of “capability” varies. Depending on the source, capability may refer to the military objectives, the military tasks needed to achieve these objectives, the means of conducting these tasks,[7,8] or the resources used to deliver or demonstrate the capability. Consequently, models representing one of these definitions and aspects of capability may cause a misunderstanding within the other communities of planning, building, maintaining, and operating the military capability.[9,10] The focus of this paper is to apply selected systems thinking tools and methods to develop consistent set of simple conceptual models that define and link the model types of military capability to support capability planning and further work in the development of quantitative capability definition and optimization.

Based on this introduction, the article is organized as follows. First, in Subsection 1.1, we describe the design problem to be approached with CBP. In Subsection 1.2, we introduce five categories of capability models and examples of them. We then define in Section 2 the aspects of the systems theory, systems thinking and system definition approaches relevant to establish a methodology to the modeling of the military capability and the defense system. In Section 3, we apply the systems approach to suggest capability models for tackling the challenges in capability planning, that is, the definition of the quantitative capability need and the description of the subsystems with capability parameters, so that it will be possible to solve how real-world subsystems are to be combined to satisfy the capability needs and constraints. The models to define and organize the CBP terms and planning elements are a conceptual model of the defense system functionalities (Subsection 3.1), a high-level data model (Subsection 3.2), and a class diagram (Subsection 3.3). An example of the parametrization of the class diagram is presented using an Army Armored Brigade Combat Team. In Subsection 3.4, we propose a high-level data model to define how the enemy degrades the capability. The model is defined first to verify the coherence of the modeling work and second to establish a concept for the ongoing work for the application of mathematical methods to capability analysis and optimization, which is outside of the scope of this paper. In Section 4, we discuss the proposed models and in Section 5 draw conclusion, and suggest further research.

1.1 | Definition of the capability planning problem

In this section, we discuss CBP when a capability is defined as an effect or a function to execute tasks and as systems; the third and fifth categories in Anteroinen's classification[9] are further discussed in Subsection 1.2. To focus on the military system, or military unit, structure definition and future mathematical modeling, only the physical components of the system, that is, personnel and materiel, and their relation to the capability are considered. The impact of the environment – weather conditions, terrain, surrounding infrastructure, and other military units – is omitted to focus on the interactions between the two forces; although in practice, the environment and other wider system issues are obviously relevant. Typically, CBP processes define the relevant aspects of the environment and types of military operations to develop collection of possible planning situations for the capability requirements definition, capability assessment, and solution selection.

A military unit or an organization consists of its personnel and the materiel. Organized and trained personnel equipped with appropriate materiel represent, have, or produce capabilities. When two military units fight against each other, they activate their capabilities to cause degradation to the enemy's materiel and personnel. To define the capability need and to plan how to implement it as military units or systems, the problem to be solved is: how will the capability evolve during the interaction with the enemy, and whose capabilities are poorly known? Figure 1 illustrates the dynamic interactions of own military combat and sustainment capabilities under the effect of enemy capabilities. Our capability degrades the enemy personnel and materiel which has an impact on the enemy capability; and the enemy capability degrades our personnel and materiel which has an impact on our capability. External resources, that is supply, and sustainment capability maintain the degraded personnel and materiel. As shown in the causal loop diagram, the enemy capability can be represented symmetrically to our own capability. Further modeling in Section 3 is focused on our own capability, indicated by the dashed line in Figure 1, for purer representation.

The defined illustration of our own capabilities, delivered by personnel and materiel, indicate complex structure and interactions between the functions and the elements related to capability. Furthermore, real military units, typically consist of smaller formations, have several capabilities, consist of a large amount of different materiel and personnel, and interact with the environment. Next, we introduce categories of existing capability models and examples of their implementations.

1.2 | State of art – Existing capability models

Based on Anteroinen's work,[9] the existing capability models can be classified into five categories depending on their viewpoint or planning level. Below, we introduce these categories and existing capability models, focusing on the application of the capability models and structures in different organizations and their CBP processes.

Military capability as an instrument of foreign policy. Capability is considered a government's political tool in its international relations. In the doctrine of the US Armed Forces,[11] military capability is described as one of the instruments of national power. NATO considers this capability model as an instrument of alliance strategy.[12] The national power and the alliance strategy consist of diplomatic, informational, military, and economic (DIME) instruments.

Capability as fighting power through military units. Capability is considered a military unit, that is, a force element, which produces the military power to achieve desired operational effects. The Finnish Defence Forces' capability model[13,14] includes a view to define operational effects. The real-world fighting power of a military unit consists of a way to fight and the ability to induce people to fight against a defined enemy and the means, that is, resources, to fight.

Capability as an effect or a function to execute tasks. Capability is an ability or a capacity to carry out a set of tasks. Task is defined as an action or an activity specifically assigned to an individual or organization[11] or a discrete event or action that enables a mission or function to be accomplished by individuals or organizations.[15] Capability is also seen as an ability to achieve a desired effect.[7,8] These functional capability models are used in CBP approaches to avoid a potential bias to a particular capability solution and to develop

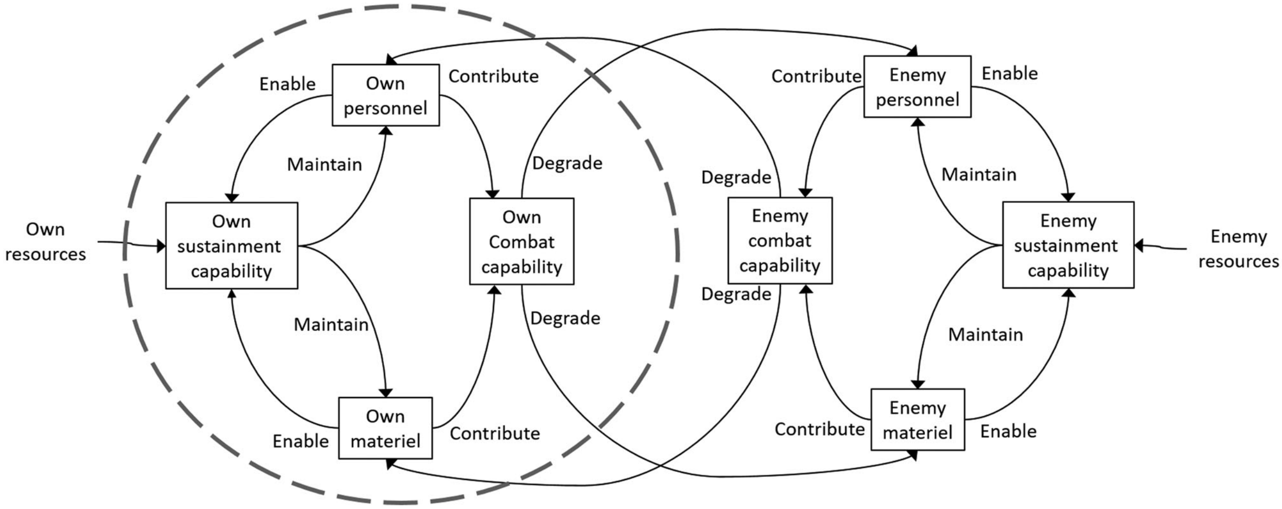

FIGURE 1 Capability degradation and sustainment

solutions suitable for a wide range of operations in different geographical locations.[1,2,4] The US Joint Capability Areas (JCA)[8,16,17] and NATO capability codes (NCC)[18] are examples of predefined functional capability taxonomies. Additionally, the Finnish Defence Forces' capability model[13] has a functional capability model and utilizes a nationalized version of the JCA taxonomy, and the latest version[14] uses the NCC taxonomy to support the definition of functional capabilities.

Hierarchical task lists such as the NATO task list[15] and European Defence Agency's Generic Military Task List[19] are defined to support the identification of the tasks to be executed. The US DoD Universal Joint Task List (UJTL)[20] together with each service branch's specific task lists provide a catalog of the functional tasks, conditions and dimensions for all levels of planning.[16] In the case of US DoD capability planning process, the functional capabilities are mapped to tasks.[16]

Capability as a weapons system or a platform. Capability is a physical system. This classical capability view is mainly used by system operators and developers or to assess military operations or in the threat evaluation and weapons allocation.[9] However, based on the previous capability model definitions, the weapon system or a platform is a building block to implement the capability rather than the capability itself.

Capability as systems. Capability is a conceptual system, defined as a set of components and their interdependencies, and used in planning, building, and management of real-world capability solutions, such as military troops. This model type considers components such as personnel, information, and some functionalities required to produce the capability instead of just focusing on the platforms and other technical components of the capability. Capability as systems[9] models typically cover components such as doctrine, organization, training, materiel, leadership, personnel, facilities, and policy. An example of this is the US DOTmLPF-P model,[5] in which the lower case "m" highlights the importance of nonmateriel capability solutions, to be compared to an earlier version of a capability system model, DOTMLPF.[16] Another example of a capability system model is the NATO model DOTMLPFI,[21] where interoperability (I) replaces policy. The UK TEPIDOIL is a similar model consisting of training, equipment, personnel, information, doctrine and concepts, organization, infrastructure, and logistics.[7,16] The Finnish Defence Forces' capability model[13] considers capability as a system of personnel, materiel, doctrine including tactics, techniques, and procedures (TTP), organization, and information (PMDOI). The PMDOI model represents only the minimum set of components required to define the capability system, that is, the system elements, structure, functionality, and the inputs, outputs and the system element interactions. However, the DOTMLPF and TEPIDOIL models also include processes and attributes of the system elements. These "capability as systems" models may be seen as building blocks or areas to be developed to provide functional capabilities such as command and control or intelligence. Because of the heterogeneity of the components, these "capability as systems" models are typically referred to as "lines of development[9]" or as "resource models" that contain "means" and "ways" factors in addition to system elements.[16]

Based on the different context-dependent capability models, Anteroinen[9] proposed a comprehensive capability metamodel (CCMM). The model integrates existing capability models and represents them as a hierarchical order using the Zachman Framework for Enterprise Architecture.[22] The CCMM also includes the horizontal definition of the primary application area, the stakeholders, relevant processes, temporal features, and the motivation of each capability perspective.

Park et al.[16] proposed an integrated capability framework that brings together capabilities at the different levels of the organization, the current force operation view, and the forces to be developed in the future. The framework supports the management of complicated relationships by connecting the capability planning elements, that is, the capability models together. The framework includes a logic where the organizations perform the operations consisting of tasks. The tasks are fulfilled using the functional capabilities that are provided by the systems consisting of the resources.

Enos[17] proposed a modification of the X-Matrix enterprise architecture tool to support high-level resourcing decisions in capability development. The X-Matrix connects the capability development programs, functional capabilities (JCA), and tasks (UTJL).

Joint Defence Planning Analysis and Requirements Tool Set (JDARTS) is a software tool to support CBP in NATO and nations. In JDARTS, the capability is described as an ability to perform a certain task. According to Hennum and Glærum,[23] JDARTS solves for fulfilling the capability requirements, that is, performing the tasks, by a combination of the current and future units and platforms in the force structure at the lowest cost as well as considering other constraints.

Kuikka et al.[24–27] proposed a system of systems (SoS) model to evaluate the impact of technologies and systems on military tasks and military capabilities. The conceptual and mathematical models define the relationship between technologies, systems, and capabilities. The model includes a novel idea of describing the concept of a capability as a probability of mission success. The system structure is built up using the serial and parallel arrangement of the systems. The model supports the analysis of the impact of technologies and systems on the capabilities. Furthermore, the model could be utilized in capability management.[25]

The Guide to the Systems Engineering Body of Knowledge[28] defines capability as "the ability to do something useful under a particular set of conditions." From the (systems engineering) enterprise perspective, organizational, system, and operational capability are identified. In the capability model, the individual competence of the people enables organizational capability, which enables system capability. Moreover, the system capability enables the organizational capability of the enterprise, and this influences operational value. The ultimate objective of these capabilities is to enable an enterprise to satisfy stakeholders' expectations related to a problem situation.

Park et al.'s framework,[16] the Enos' matrix,[17] the logic of the JDARTS planning tool,[23] and SEBoK model[28] connect the other capability model categories defined by Anteroinen,[9] except for the "military capability as an instrument of foreign policy." The category "capability as fighting power through military units" is not explicitly included in the Enos' matrix. In Park et al.'s framework, the military unit is implicitly presented as the systems and resources. Kuikka et al.'s model[24–27] focuses on future systems; therefore, systems are presented as generic objects characterized by functional capabilities rather than as specific system components. However, the relations between the capability models follow the same logic as the other models. SEBoK[28] defines the capability model for an enterprise aiming to deliver operational capability and to improve a stakeholder's operational value. Compared to previous military capability models, the SEBoK model highlights the people and the organizations' engineering skills and practices to develop, supply, and operate the systems to deliver an operational capability. Table 1 summarizes presented capability models, their representation, and covered capability considerations.

As a summary, there is a variety of existing capability models, developed to support specific viewpoints and dedicated purposes. None of the presented models meets the requirements of consistent and traceable CBP, from the desired military effect to capabilities and down to system elements. Next, we introduce selected systems approach concepts, methods, and tools to support the development of further understanding of military capability by system modeling.

2 | METHODOLOGY – SYSTEMS APPROACH AND MODELING

This section presents the methodology to be applied in our capability modeling for CBP. We first give a brief introduction to the systems approach and briefly review the SoS and related concepts. We then introduce tools to support the development of the capability models. Finally, we represent a high-level data model to establish relationships between different capability models as the methodological foundation for the modeling work in Section 3.

2.1 | Systems thinking

Systems thinking can be categorized based on whether the system is hard or soft. According to Reynolds and Holwell, in *hard systems thinking*, the systems represent real-world entities,[29] and according to Hitchins, it is often used by engineers to find the best possible solution to a given problem within given constraints.[30] In contrast, *soft systems thinking* focuses on the process of understanding the complexities of the real world, including human and cultural aspects, rather than aiming to describe some part of the real world. It utilizes systems models as learning systems for the process of understanding the world and proposing purposeful actions for improvement, considering differing stakeholder views. Soft systems methodology (SSM) is the result of 30 years of research filling the gap between traditional systems engineering and management problems.[31–33] A third tradition is *critical systems thinking* that addresses the power relations and how they affect which problems are addressed and how they are observed.[29] However, the power relations between different stakeholders are not studied in this article.

Anteroinen,[3] who proposed how a systems approach can be applied to support the development of military capabilities, defines the methodology comprehensively. According to Anteroinen, the systems approach and systems thinking is a metadiscipline to solve problems based on the practitioners' perspective and competence to recognize the world holistically as a set of elements and their interrelations. There are several systems approaches to address complex problems, to understand complex behavior, and to propose future systems and their behavior. The SSM,[31,33] causal loop diagrams,[34,35] and strategic options development and analysis (SODA)[29] are examples of the methodologies of the systems approach and all members of approaches to problem structuring methods (PSMs),[36] which are particular forms of soft operations research.

2.2 | System terms and concepts

"System" is a widely used and broad concept. Hitchins[30] defined a system as a complex whole, which is a set of connected things or parts and an organized body of material and immaterial things, among other definitions.

TABLE 1 Existing capability models

Capability model	Representation	Capability considerations
Doctrine of the US Armed Forces,[11] NATO Allied Joint Doctrine[12]	Textual	Instrument of foreign policy
Military unit description	Textual, number of units and their elements	Fighting power through military units
The US Joint Capability Areas JCA,[8,16,17] NATO capability codes NCC[18]	Textual	Effect or a function to execute tasks
Weapons system or military platform specification	Textual, drawings, diagrams, performance parameters	Weapons system or a platform
DOTMLPF[16] (US), DOTmLPF-P[5] (US), DOTMLPFI[21] (NATO), TEPIDOIL[7,16] (UK), PMDOI[13] (FI)	Textual	Systems
Comprehensive capability meta-model CCMM	Framework (matrix)	Above mentioned considerations and their application area, the stakeholders, relevant processes, temporal features, and the motivation
Park et al. capability framework[16]	Framework	Resource – systems – functional capability – task – operation
Enos' X-Matrix[17]	Matrix	Development program – functional capability – task
Joint Defence Planning Analysis and Requirements Tool Set JDARTS[23]	Textual, capability parameters	Military unit – functional capability – task – mission
Kuikka et al. conceptual and mathematical models[24–27]	Diagram, mathematical	Physical system – functional capability – task
SEBoK enterprise capabilities model[28]	Data model	People – organization – system – operations

A *system* consists of *elements* and *relationships*, which both have their *attributes*. A system element is a part of the system that has *input* and *output* interfaces, and the *process* that produces the output from the input. The relationships link the outputs of system elements to inputs of other elements.[30] The system may be divided into *subsystems*, which are also systems with the system elements, their attributes, and all other components and features of a system. This is a *hierarchy* in which system entities as wholes consist of smaller entities that themselves are wholes. Consequently, the system, the subsystem, and the system element are relative; the system at a certain level of hierarchy is an element at another level.[30,37,38]

The *environment* of a system is a set of elements, which are external to the system and may cause a change in the system's state,[39] or everything outside the system having only input or output with it.[37,38] Often, it is practical to define *system of interest* (SOI) as the subsystem in which our actions are targeted to. This defines a boundary[37,38] between the SOI and environment and the rest of the system, for example, the other actors' systems of interest in the system. However, the boundary is a decision to focus the interest rather than an objective property of the system. Eventually, the SOI will impact the environment, thus extending the system to include the environment and moving the boundary. The environment itself can be modeled as a separate system or systems. The decomposition into the environment and the SOI is determined by which of the relationships between the elements are included in the analysis.

In systems thinking, the system is more than the sum of its elements. The *behavior* of the system cannot be understood only by analyzing the system elements. This principle of *emergence* and *emergent properties* is fundamental to systems thinking.[30,37,38,40]

Closed systems are those in which all elements receive inputs, that is, those with no environment. *Open systems* receive information, energy, and matter from their environment.[30,37,38,40,41] Real-world systems are always open, and thus this categorization reduces the question of defining system boundaries in the system analysis.

The concept of *feedback* is common to all branches of science considering systems and their regulation and control, such as cybernetic theory.[42] The complex behavior of the systems results more commonly from the feedbacks between the elements of the system than from the complexity of the elements.[34,35]

The SoS paradigm has been applied widely in the literature since the mid-1990s. Slightly differing definitions have been presented, and the validity of the SoS concept as a structure of the system in its own right has been questioned by system scientists, for example, by Hitchins.[45] This is because SoS is based on the definition of a system, and the expression of the SoS can be seen as a hierarchy. In the literature, five features to distinguish the SoS from systems that have been proposed[43,44,46,47]: operational and managerial independency, geographic distribution and emergent behavior of the component systems, and lastly, evolutionary developing of SoS. Federation of systems (FOS) is a special type of SoS, characterized by the absence of the central authority and a higher level of independency.[43] The family of systems (FoS) is an organization of the same type of systems, such as a product line or a family of missiles, instead of being another type of system.[48]

A defense system, its elements, and its capability are complex, increasingly interconnected by the information flows and consist of interacting system elements. Hence, the general system terminology is applicable when analyzing the defense system and its capability.

Therefore, we do not apply the concepts of SoS, FOS, and FoS in the following work.

2.3 | Data modeling and architecture

Hoberman et al.[49] defined a data model as a composition of the symbols of things, places, and people of interest to a business. The goal of the data model is to translate complex and technical things to an understandable set of visual diagrams representing different levels of detail. Data models can be classified into very high-level, high-level, logical, and physical models to be used, correspondingly, by business management, analysts, architects, and developers. Very high-level and high-level data models may also be called conceptual data models.[50] Different modeling notations, such as information engineering (IE), entity relationship (ER), integrated definition for data modeling (IDEF), barker, object role modeling (ORM), and unified modeling language (UML), have been formalized. However, it is crucial to use the notation that is the most intuitive for the audience.[49]

The UML is intended for the design, implementation, and analysis of software-based systems, business, and other similar processes.[51] The early versions of UML have been applied to conventional systems engineering with the aim of defining a standardized notation.[52] Later, the first specification of the systems modeling language (SysML)[53] was introduced as a general-purpose language for systems engineering applications. We find SysML best suited for the design of the structure and high-level functionalities of real world physical systems. Therefore, we use UML class diagram instead of SysML block definition diagram to define capability consisting of concepts[39] such as system, environment, properties, relationships, and functions.

Architectural description

An *architecture* is defined as "fundamental concepts or properties of a system in its environment embodied in its elements, relationships, and in the principles of its design and evolution." Consequently, an *architecture description* is a work product that expresses an architecture. An *architecture framework* is the foundation for applying architecture descriptions in some application areas or communities.[54] The architecture framework provides a structured approach to complexity management in networked systems, enables communication between stakeholders, and supports system analysis and design of the future and existing systems. Zachman Framework for Enterprise Architecture[22] is an example of such kind of generic framework. DoDAF,[50] MODAF,[55] and NAF[56] are architecture frameworks for the defense system analysis and definition, in particular for command, control, communications, computers, intelligence, surveillance, and reconnaissance systems (C4ISR). These architecture frameworks consist of *viewpoints* that define the rules for a set of *architecture views* representing specific system concerns. *The architecture view* consists of one or more *models*. The *metamodel* underlying the architecture framework defines the relationships between the elements in different viewpoints. DoDAF *metamodel*[50] DM2 has a conceptual data model diagram (DIV-1) to communicate the concept of the high-level data constructs of the architectural description to the managers and executives. The MODAF *metamodel*[57] defines in detail the data model of each architecture view.

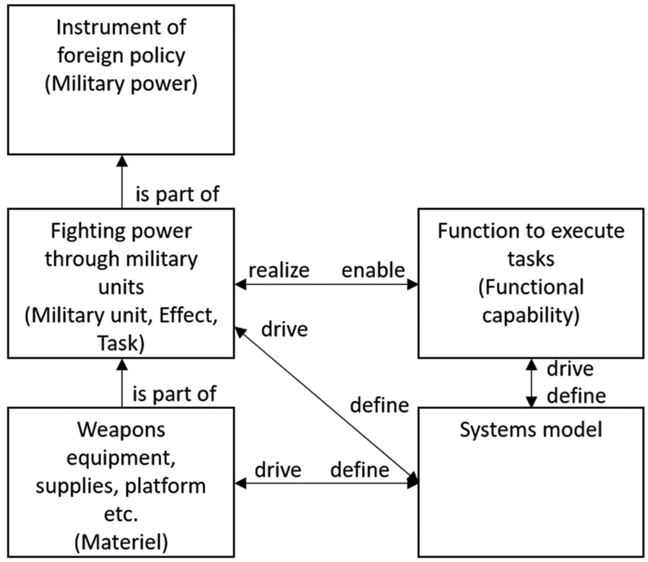

FIGURE 2 Capability model types and their relations

Stakeholders need appropriate support to facilitate their communication between each other and with the planning specialist community to benefit from the CBP approach. The role of military experts is not to become involved with complicated tools and methods but to provide vital domain expertise to the planning process. The architecture framework is an excellent tool to define the current defense system, define the capability needs, and describe the system solution. Unfortunately, precise but complicated mechanisms of the architecture frameworks and related metamodels with sophisticated notation do not necessarily explain the relationships between the capability viewpoints and elements in an apparent way. Consequently, the architecture views and typical CBP processes are not linked in an obvious way. Therefore, the military experts and decision makers involved in capability planning are only rarely able to deepen their understanding or to define the solution by applying architecture frameworks without personnel specialized in these tools and methods. A simpler definition of the capability, compatible with the process, is required.

2.4 | Capability model framework

In Section 1, we reviewed five capability model types proposed by Anteroinen[9] and how the capability model types are linked based on Park et al.'s[16] and Enos's[17] studies and the JDARTS analysis tool.[23] Figure 2 suggests a high-level data model, which represents abstractions of capability definition problem. Data model describes the capability model types and their relationships as a framework for capability and defense system modeling. The notation was chosen to keep the representation informative, but readable for wider audience, and therefore it does not follow any specific approach but has some commonalities with cognitive mapping[58] for SODA.[29]

The real-world instances of the capability are on the left side of the diagram, and the conceptual model types are on the right. The first version of the model has been applied by Koivisto and Tuukkanen[59] for an R&D-based bottom-up process and conceptual future system, the cognitive radio. Original model described that the systems model defines materiel, fighting power, and functional capabilities. Actually, it is two-way relationship: creating the system model driven by desired capability and the needed resources, and then using the system model to predict the outcome in a specific environment and instance.

3 | GENERIC CAPABILITY MODELS

To establish a foundation for the quantitative analysis of the capability need, the solution to fulfill it, and the definition of the capability parameters in capability planning, we apply systems concepts and the framework in Figure 2 to suggest new consistent set of models for defense systems and capabilities. The notation of the models is chosen, or tailored, focusing on the readability for the audience not familiar with the specific modeling languages. The models comprise a context model defining the defense system in its environment, a data model defining and organizing the terms and the capability viewpoints related to the CBP, and a class diagram defining explicitly the capability planning elements and their relationships in CBP.

Capability planning solves for a real-world set of subsystems, which combined have the required capability and satisfy a set of predefined constraints. To support this planning process, we propose a data model to dynamically and quantitatively describe how the capability is degraded in action. The internal coherence of the other modeling work is verified with this model. In subsequent work, the real-world set of subsystems will be solved based on this model and using well known mathematical optimization methods.

3.1 | Defense system and the capability – The context model

A defense system is an open system that exchanges energy, information, and materiel with other systems, including the enemy. As a result, the defense system and its emergent behavior are altered in some way. In Figure 1, we defined the high-level dynamic interactions between the enemy and the defense units omitting, for the sake of simplicity, the defense system structure, the surrounding systems, and the environment.

We now propose a high-level model of the defense system in its environment. The model is defined in the context of CBP and national military capability. The model, as shown Figure 3, aims to provide insight regarding the interactions with the surrounding systems and environment. Notation is inspired by Flood's and Carson's[37] ideas on defining a system and chosen because of its simplicity, focus on high-level system structure and the ability to illustrate the boundaries between the systems and the environment. The model is a functional representation of the *defense system* as an SOI surrounded by the *environment*. Level of abstraction and the boundary between the SOI and the environment are based on our aim to suggest models for the CBP in the defense system level and below, that is, our actions are targeted to SOI. The *ministry of defense* system is illustrated in the diagram for the external control system and as an example of the *defense system's* interaction with surrounding systems. To keep the diagram in a simple form, the details of the enemy capability are not included in the diagram but could be defined symmetrically to own capability, see Figure 1.

The functionalities of the subsystems are defined based on the US JCA[8] with a few modifications. The capability area "Protection" is implemented in each functional system to prevent or mitigate lethal effects. JCA "Netcentric capability" is implemented in the systems to enable communication between the system elements, other systems, and between the systems and the environment. "Building Partnerships" is assumed to be provided by other systems, such as Corporate Management and Support. "Battlespace Awareness" is renamed *intelligence, surveillance, and reconnaissance* (ISR) because of the wider perspective of ISR than just a battlespace has to be covered in the defense system level. Accordingly, this information collection, processing, analysis, and production functionality is named *monitoring* in the *ministry of defense* system for the sake of understandability. The systems require communication and control activities or processes to react to changes in their environment. The core structure of the control activity includes the *monitoring* activity to evaluate the system performance and consequent *command and control* actions to change the operation of the system.

The defense system consists of, and its emergent properties are defined by, the systems, system elements, and their interactions. The model in Figure 3 represents the defense system level of the system hierarchy. Defense system may be seen as SoS, but we apply general systems terminology to maintain the scalability of the model and suitable terminology for the lower levels of the defense system hierarchy. At any level of the defense system hierarchy, a *system* represents a *military unit* consisting of *system elements*: the *personnel* and the *materiel*.

The defense system and its elements interact with the defense system *environment* through the system *inputs* and *outputs*. Consequently, the environment affects the system behavior, and the system affects the environment. At the defense system level, the environment consists of other systems such as enemy, partners, government organizations, other officials, and possibly the military forces of other countries. The *conditions* surrounding the defense system consist of factors such as weather conditions and geographical factors, such as terrain, soil, and vegetation. *Enemy*, that is, a hostile nation or force is a crucial factor in the defense system environment from the capability planning point of view. This factor may affect the defense system directly, for example, by neutralizing the system elements, or indirectly, for example, through the conditions by making them unfavorable for the defense system, or affecting the government. The elements and the emergent properties of the system define the outputs of the

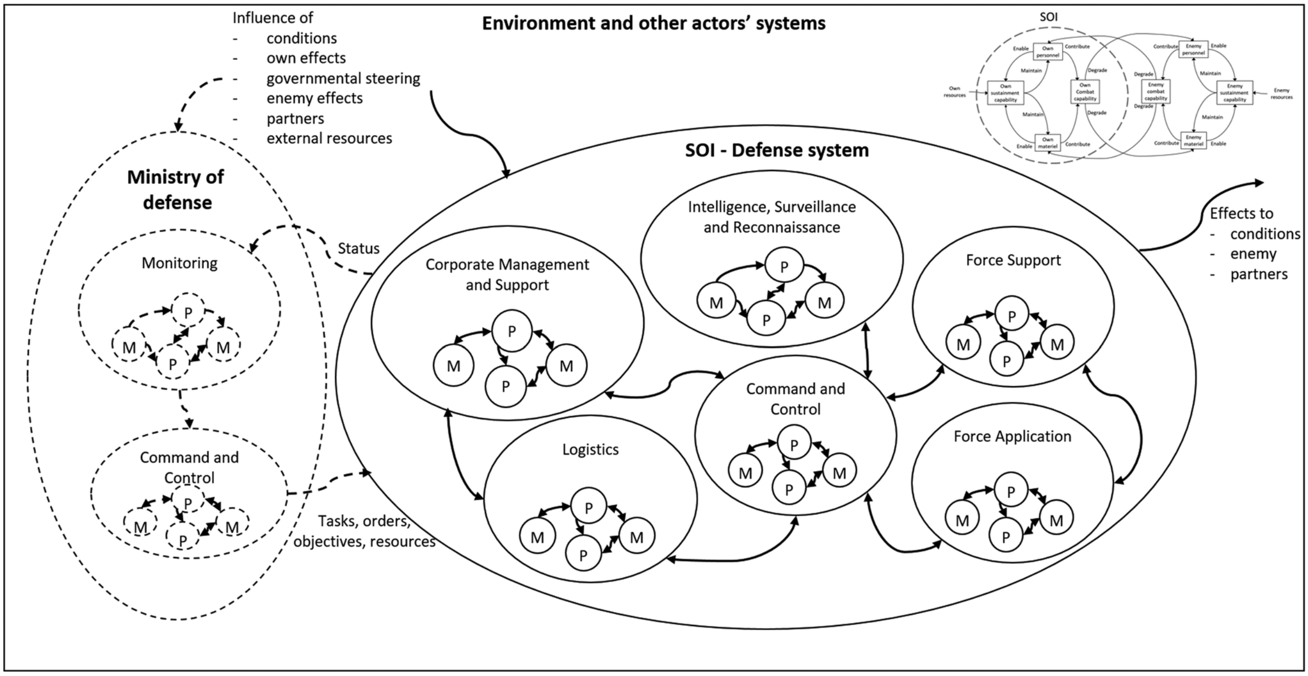

FIGURE 3 Conceptual system model of the defense system in its context. Defense system, system of interest (SOI), is surrounded by the environment and other actors' systems. The systems include interacting system elements personnel (P) and materiel (M). The linkages between the subsystems and the system elements are exemplar

defense system. These outputs are *effects* that affect the *partners*, *conditions*, and *enemy*. Defense systems outputs, own *effects*, may also affect the defense system itself via the environment. This feature can be considered a feedback loop.

The defense system has an input to receive the *orders*, *tasks*, or *objectives*, aimed to change the system behavior or the system structure. An input of *resources* is required to build and maintain personnel and materiel in the systems within the defense system. Continuous resourcing, for example, spare parts, fuel, food, energy, information, and other, is needed to sustain the defense system or else the materiel and personnel decline over time, even if the system is not used for the military operation.

We apply *capability as systems*, that is, models to verify that these aspects of the capability are taken into consideration in our context model. Table 2 collects together the components of *capability as systems* models, such as TEPIDOIL and versions of DOTMLPF. In our problem description and context model, the components are interpreted as given in the right column of Table 2.

Notably, Doctrine/TT&P is a description and implementation of the system element and system functionalities, and training is an activity by the "personnel" rather than a separate internal or external system. Organization represents a system structure and therefore implicitly exists in the system model. Information is a fundamental part of a system model as one type of the system's or system element's input or output, in addition to matter and energy. Moreover, the systems and the system elements, the personnel and the materiel, typically contain and interchange the information and are able to process it.

From this interpretation, it follows that only the "materiel," "equipment," "infrastructure," "facilities," and "personnel" are the actual system elements. Thus, in the model of Figure 3, materiel (M) also includes equipment and materiel-related infrastructure/facilities, and personnel (P) includes its leadership skills. The other components of the capability as systems–models are directly identifiable in the model.

In the early phase of the capability planning process, the conceptual system models are groupings of the system elements to provide functionality. Later, in the capability planning process, the systems are generic representations of the military units to be realized.

Next, a high-level data model is justified by a synthesis of the conceptual model of the defense system, the model types of the military capability, and the terms in the CBP.

3.2 | Capability model types and terms – High-level data model

In Section 1, the capability models were classified into five model types (see Figure 2). We construct a high-level data model, Figure 4, that identifies the pivotal terms and their relationships in CBP based on the existing capability model types and models. The model is presented with the real-world elements on the left and the conceptual elements on the right. We chose same notation as used in Figure 2, valuing the readability over formality.

Starting from the real-world elements, the first model type, *military capability as an instrument of foreign policy*, is encapsulated in *military*

TABLE 2 Systems approaches interpretation of the "capability as systems" – model components

"Capability as systems" model components	Proposed systems approach interpretation
Doctrine, concepts, tactics, techniques, procedures	Definition of function/system behavior/emergent properties of the systems
Organization	System structure (physical or functional)
Training	Function/process (performed by systems and system elements)
Materiel, equipment	System element
Leadership	Attribute of system element (personnel)
Personnel	System element
Infrastructure, facilities	System element (internal or external type of materiel)
Policy	System input (constraint on a function, on a system element or a system relationship)
Interoperability	System behavior
Information	Interaction of systems/system elements
Logistics	System functionality

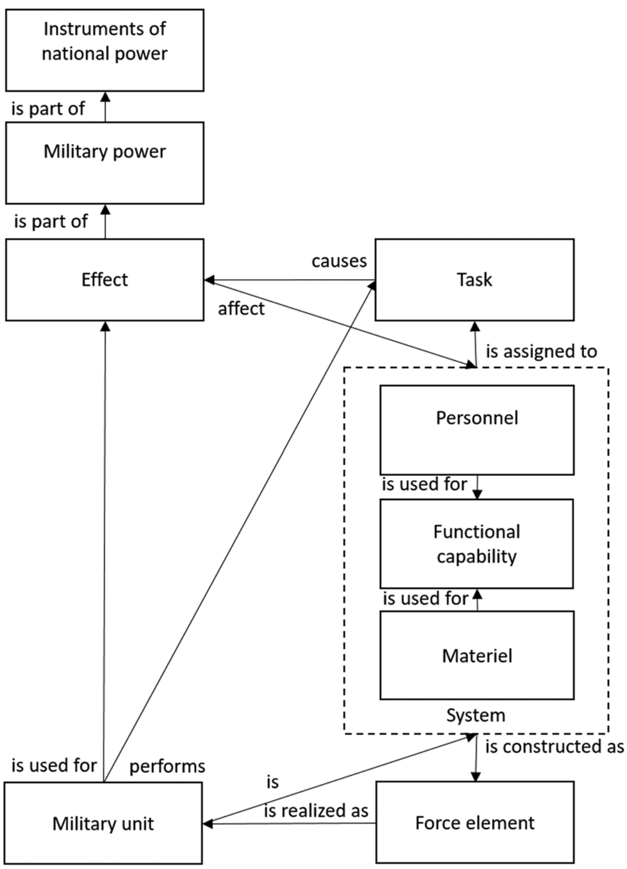

FIGURE 4 High-level data model representation of the terms and their relationships in capability-based planning

power. *Military power* is seen as an instrument of foreign policy or an extension of it. We choose *instruments of national power* as the highest level of capability. *Military power* is produced by *fighting power through military units*, which have been divided into two elements, the real world *military unit* and the real-world *effect*. This is because from the systems point of view, the former is a system, and the latter is an output of the system (see Figure 3). The defense forces are the highest level military unit, including all troops and materiel. The lower levels of the defense system hierarchy consist of military units such as commands, agencies, brigades, regiments, or battalions down to fire teams or a single soldier, depending on the country and service branch.

The defense system model hierarchy and other conceptual planning elements of the data model are presented on the right side of Figure 4. *System* is a conceptual description of the military unit and its elements *materiel* and *personnel*. In a simple, generic form, the systems model of capability may be represented as the conceptual system model in Figure 3. The highest level in the system hierarchy is the defense system. For capability development, the military units, or systems, may be organized as the defense system's subsystems, as shown Figure 3, which accordingly may be divided into the systems. All these *systems* in the hierarchy consist of *materiel*, for example, weapon systems and *personnel*.

In addition to the system elements and their organization, the functionalities and corresponding outputs are to be defined for a more comprehensive system definition. We define *capability as an effect or a function to execute tasks* as a *functional capability*. In the CBP process, *functional capability* defines the capability potential of some current or planned *military unit* or a system consisting of *materiel* and *personnel*. Eventually, the capability development process must define the implementation of the systems in terms of real world military units. The concept of *force element* defines the final system structure, that is, the organization of the real world *military unit* to be produced. In our data model, *functional capability* is arranged inside the SOI to represent the emergent properties of the system. When this potential or emergence is planned to cause some *effect*, the *systems*, specifically their *functional capability*, are assigned to a *task* in the planning process. Furthermore, the *effect* is produced when the *military unit* performs the *task*.

The role of the high-level data model, such as Figure 4, is to visualize pivotal terms and their relations.

We acknowledge that there are more connections between the elements than portrayed, but the most important connections from the CBP process point of view are presented. In CBP, our model aims to provide a structure for finding novel and cost-effective capability solutions rather than just choosing the most obvious, traditional, and possibly an expensive one.

3.3 | Capability-based planning elements – UML class diagram

3.3.1 | Definition of the model

Next, we define the systems approach concepts such as the system, environment, properties, relationships, and functions as a UML class diagram. UML class diagram is chosen to model these aspects precisely and using established standard to support possible future activities in developing information systems for capability management and ongoing work on mathematical modeling. The notation itself, including the specifically defined types of relationships and the concepts such as *class* and *instance* , makes the model more complicated than previous models. The class diagram aims to capture in a single model the crucial aspects of the military capability, such as various capability model types, instances of the capability evolving during the capability development process and in the operating capability. The character of the capability depends on the level of organization and on the military unit or on the system that delivers the capability.

The class diagram in Figure 5 integrates the defense system planning elements identified in the conceptual system model shown in Figure 3 with the capability model types in Figure 4. As we focus on the defense system, *national elements of power* and *military power* are considered as a part of its environment and excluded from the diagram. However, we suggest that national power could also be represented via effects.

The class diagram representation of the CBP elements establishes concepts as follows. *Task* represents something needed for an effect. *Tasks* have two instances, that is, during planning, the task is an *intended task*. When a *task* has been successfully executed, it represents an *effect*. Therefore, if the desired *effect* is not achieved, then the corresponding *tasks* were not executed appropriately. If several actions are needed for an *effect*, then they are referred to as subtasks. A *task* and its instances depend on own, enemy, and partner capabilities and on conditions such as terrain.

A *functional capability* is an abstract element that defines the capability potential and enables *tasks*. *A functional capability* has two instances, namely, *planned capability and real capability*. *Planned capability* is the capability goal at the beginning of the planning process, and *real capability* is the capability level later in the planning process after the trade-off analysis, after realization, or after the operational use and degradation of the capability. Primary capability is the fundamental purpose of the capability and enabling capabilities are those required to enable the primary purpose of the capability. This simplification is based on the principles of NCC[18] in which concept of capstone, principal, and enabling capabilities is used. In practice, several functional capabilities may be required for one task and one capability may be used in several tasks. The concept of functional capability is only for CBP and is not applied in typical operational planning processes or when operating.

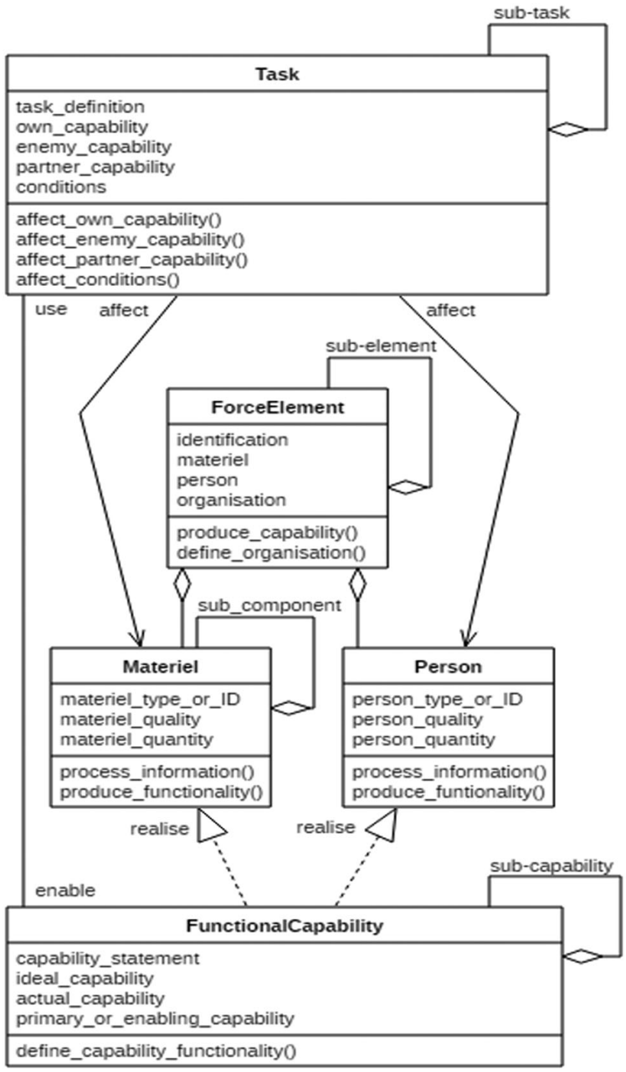

FIGURE 5 Unified modeling language (UML) class diagram representation of the capability-based planning elements

Personnel, consisting of one or more individual *persons*, and a *materiel* are system elements that realize *functional capability*. The own and the enemy *effect* affects *person* and *materiel* when the *intended task* has been executed. *Person* and *materiel* have two instances. During the capability development process, *person type* and *materiel type* are established, and the required properties are defined. When the capability is realized, *person* and *materiel* are personalized and individualized to real-world objects. Consequently, *functional capability* is realized by and determined by the composition of the *persons* and the *materiel*.

A *force element* is an organization of *persons* and *materiel*. The *force element* defines the system structure, that is, the organization of the system elements in the systems. In addition to the military force structure view, defined by the force element, many other system structure representations shall be considered in the capability planning process, such as different functional organizations. The *force element* has two instances, similar to the case of the *person* and *materiel*. During capability planning, the *force structure* is defined using *person types*

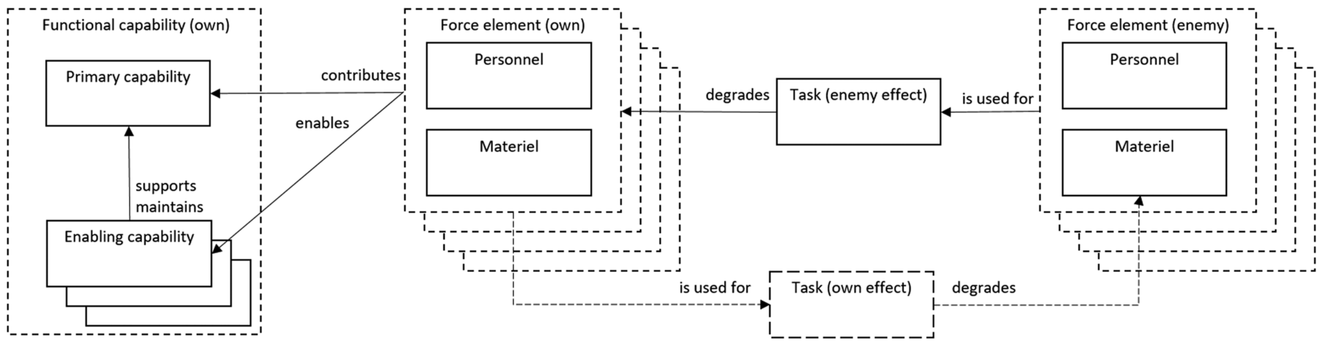

FIGURE 6 High-level data model of the degradation of capability

and *materiel types*, whereas the real-life *military unit* is an organization of *real persons* and *real materiel*.

In practice, predefined or existing force elements or traditional line organization structures are the building blocks of capabilities instead of the materiel and personnel system elements. This structure simplifies the capability and operational planning processes but has the risk that the predefined structures lead to capability implementations that have far suboptimal costs. Furthermore, if very high-level force elements are used in planning, then the modularity of the force structure may be compromised.

3.3.2 | An example of the parametrization

We generate a real-world example of the model by populating the UML class diagram with actual data. This model covers the needs of all levels of planning, including planning the whole defense system. An Army Armored Brigade Combat Team (ABCT) is particularly suited as an example because of its fairly large size and many capabilities. Furthermore, the required information on ABCT is publicly available.[60] Table 3 provides the data for a generic ABCT military unit and for a specific real-world unit 1ABCT of the 1st Infantry Division. The former values are based on the literature,[60,61] and the latter are inferred from the organization structure in the Fort Riley's[62] website.

3.4 | Dynamics of degrading capability – High-level data model

The conceptual system model of the defense system, Figure 3, defines the inputs and outputs. These inputs and outputs are implicitly included in the UML class diagram as the attributes and operations to enable the defense system's interaction with the environment. In the model of dynamically degrading the capability, Figure 6, the enemy force element structure and the relations between the planning elements are symmetric with the own system. Other interactions between the force elements and environment are excluded to keep the model in a simple form and at a high level to facilitate ongoing mathematical modeling. The model follows the notation used in previous high-level data models and represents in a simplified way the relationships between the planning elements in the situation where the *enemy effects* are directed to affect *own functional capabilities. Enemy force elements*, consisting of *personnel* and *materiel*, perform the *task*, which is realized as an *effect*. *Force elements* represent a set of military units in an arbitrary level of the defense system hierarchy and the force structure. The *enemy effect* degrades the *own force elements* and consequently reduces *own functional capability*. This degradation can be seen as a function affecting the capability description, Figure 5. Correspondingly, the *own force elements* are used to perform *tasks* to cause *effect* to the *enemy force element*, thus reducing the *enemy functional capability*. *Functional capability* can, for example, be modeled to consist of a relevant set of the *functional primary* and *enabling capabilities*, and *effects* can be modeled as reductions in these capabilities. Defining such structures and functions mathematically leads to an optimization or game-theoretic formulation of the capability operation. Solving for the optimum or the game equilibrium with given own capabilities allows assessing the performance of a collection of functional capabilities under scenarios of enemy action or capabilities. In principle, this allows designing the collection of functional capabilities optimally, with given resource constraints.

4 | DISCUSSION

The focus was to propose defense system and capability models that could be applied at all levels of the defense system. From a technical point of view, the models are scalable and applicable for any defense system – own, partner, or enemy. However, the most beneficial feature of the conceptual models is that they generalize and group different elements of the capability. It is conceivable that applying the models to very small-scale formations would lose the forest for the trees. In addition, the abstracted concept of capability may be questionable for such formations, and equipment performance and personnel skills would be more meaningful measures. In a partner or enemy defense system, this is not the case in practice, as typically only a higher level of detailed information is available for the modeling.

We defined the model structure for the dynamics of capability degradation. In real contact with the enemy, the units have the ability to recover and maintain the personnel and materiel to compensate for the degradation. In addition, depending on the degradation dynamics, the unit may be provided with an external supply of the personnel,

TABLE 3 ABCT data for two instances of the military unit and its capability

Class, attributes, and operations	Instance and state in capability planning	Instance and state in operations	Remarks
Task	**Intended task**	**Effect**	
Task_definition	ART 2.4.1 Conduct Lethal Direct Fire Against a Surface Target[a]	60% of the enemy performance degraded due to lethal direct fire attack[a]	A measure of task is used to derive the effect
Own_capability	3000	2500	Own capability value in arbitrary units
Enemy_capability	1000	1500	Enemy capability value in arbitrary units
Partner_capability	0	0	Partner capability value in arbitrary units
Conditions	0.8	0.8	Favorability factor of the conditions, such as weather and terrain
Functional capability	**Planned capability**	**Real capability**	
Capability_statement	Force application[b]	Force application[b]	ABCT has multiple capabilities to enable fairly independent operating of the unit
Ideal_capability	5000	4500	Capabililty value in the arbitrary units before the trade-off and after the implementation
Actual_capability	4500	3700	Capability value in the arbitrary units after the trade-off and current capability value of the real unit
Primary_or_enabling_capability	Primary	Primary	Units are typically assigned to tasks based on their primary capability
Materiel	**Materiel type**	**Real materiel**	
Materiel_type_or_ID	M1A2 ABRAMS MBT	M1A2 ABRAMS MBT SN. 12345678	Example: Abrams M1A2 Main Battle Tank
Materiel_quality	100%	100%	For example: Overhauled and tested
Materiel_quantity	87	1	Force element contains hundreds of the materiel types
Person	**Person type**	**Real person**	
Person_type_or_ID	SSG 19K30 TANK CDR M9	SSG T.C. Mander	For example: Tank Commander
Person_quality	100%	80%	For example: Training not completed
Person_quantity	36	1	The force element contains hundreds of the person types and about 4700 real persons
Force element	**Force structure**	**Military unit**	
Identification	Army Armored Brigade Combat Team (ABCT)	1ABCT, 1ID	Generic unit and specific unit
Materiel	100%	90%	For example, part of the materiel under the mainetenance
Person	100%	80%	For example, some positions without assigned personnel

(Continues)

TABLE 3 (Continued)

Class, attributes, and operations	Instance and state in capability planning	Instance and state in operations	Remarks
Organization	Brigade Headquarters; Fires (Artillery) Battalion; Cavalry Squadron; Combined Arms Battalion (3); Brigade Support Battalion; Brigade Engineer Battalion	1ABCT Headquarters and Headquarters Company; 1st Battalion, 5th Field Artillery; 1st Squadron, 4th Cavalry Regiment; 1st Battalion, 16th Infantry Regiment; 2nd Battalion, 34th Armored Regiment; 3rd Battalion, 66th Armored Regiment; 101st Brigade Support Battalion; 1st Engineer Battalion	

[a]Derived from The Army Universal Joint Task List.[20]
[b]Derived from Joint Capability Areas.[8]

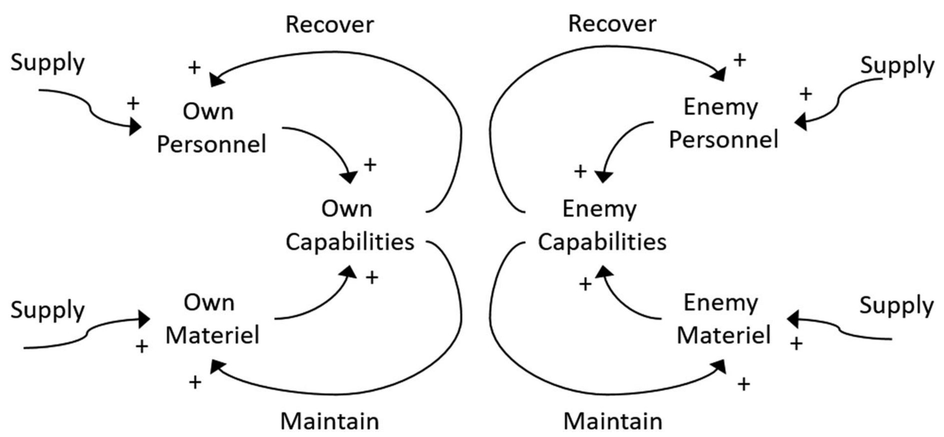

FIGURE 7 Causal diagram for supply and capability recovery

and materiel is needed. Such capability sustaining dynamics are not included in the current model Figure 6, but Figure 7 illustrates how the model can be expanded to include them.

We applied classical systems thinking concepts. The problem was defined with a soft systems approach. Soft systems approach was used also for defining the capability, especially when considering its dynamic behavior, despite the fact that the data models and UML class diagram are more part of hard than soft systems tradition. The concepts of the SoS, FOS, and FoS may be used for the definition of the defense system and are used in systems engineering practices. However, these concepts are related to managerial and engineering aspects rather than to the system structure and behavior definition.

We verified with the “capability as systems” approach (DOTMLPFI and its variations, TEPIDOIL) that all these aspects of the capability are included in the context model of the defense system and capability, Figure 3. As shown in Table 2, the components of this approach are a rather mixed collection of different aspects of the capability, such as the system elements, attributes, capabilities, or functionalities. Thus, these approaches do not represent a single logical entity. From the systems thinking or architectural design point of view, this makes their role in capability modeling questionable. Nevertheless, these models are useful as a checklist for the program plan, as an example.

Next we analyze how the proposed models support the CBP process from the following perspectives:

1. Coherence with the CBP process stages
   Stojkovic and Dahl[63] proposed a generic long-term defense planning methodology based on 10 existing process models. Their process model consists of eight stages: Political Guidance Analysis, Environmental Assessment, Mission Analysis, Planning Situations Development, Capability Requirements Determination, Capability Assessment, Options Development, and Solution Selection. Table 4 compares the planning elements in the four capability models proposed here to the stages in the generic planning process. Each process stage is supported by one or more capability models. Furthermore, the way in which the elements in the high-level data model are connected to those in the class diagram is consistent with the sequence of the process stages.
2. Support for defining the outputs of the process stages
   Table 3 shows that all the outputs of the stages can be expressed as the elements in the proposed set of capability models. This holds

TABLE 4 Support of the proposed capability models for the capability definition in the generic CBP process

Process stage	Capability related stage output	Capability model	Relevant capability model elements
1. Political guidance analysis	Defense missions	CM, HLDM, CD	High level tasks definition
2. Environmental assessment	Future worlds	CM	Environment and surrounding systems definition
3. Mission analysis	Task structure	HLDM, CD	Task structure
4. Planning situations development	Planning situations	CM	Environment and surrounding systems definition
5. Capability requirements determination	Capability requirements	HLDM, CD	Functional capabilities definition
6. Capability assessment	Current capabilities, capability gaps	HLDM, CD	Current and future functional capabilities, force elements, materiel, and personnel
7. Options development	Capability development options	HLDM, CD, DHLDM	Own and enemy functional capabilities, force elements, materiel, and personnel
8. Solution selection	Long term plan	HLDM, CD	Tasks, functional capabilities, force elements, materiel, and personnel

CM Defense system and the capability – Context model. HLDM Capability viewpoints and terms – High Level Data Model. CD Capability based planning elements – UML class diagram. DHLDM Dynamics of consuming capability – High Level Data model.

in particular to the stages that output capability definitions, namely defense missions, task structure, capability requirements, current capabilities, capability gaps, and capability development options. The stage outputs future worlds, planning situations, and long term plan are supported in their capability definition aspects, whereas they provide less support when defining the surrounding systems or the operating environment.

3. Defining model element interactions
   All elements in the models are interconnected, except those in the conceptual context model. UML class diagram (Figure 5) and high-level data model (Figure 4) define the types of the relations between the objects.
4. Suitability for the capability dynamics and optimization
   The model for capability degradation and sustainment (Figure 1) is the foundation for the proposed static capability models, but also the basis for dynamic models for capability degradation (Figure 6) and capability supply and recovery (Figure 7). Thus, the static models have a natural extension to the dynamic representation of capability. The extent to which the set of models proposed supports capability optimization cannot be answered in detail and is a topic for ongoing work.
5. Adoptability for the CBP practitioners
   The terminology of the proposed models originates from the state-of-art CBP processes and capability models. CBP practitioners are familiar with these terms from the operational planning processes. As there are only four models which in turn consist of a rather small number of elements, it is presumable that the CBP practitioners could utilize the models with little burden in and perhaps further develop them to integrate them to the process. However, the authors realize that the clarity of the terms and definitions can never be overemphasized.

DoDAF[50] consists of eight viewpoints, one of which is the capability viewpoint. The capability viewpoint consists of seven models, CV-1 to CV-7. In general, the models define the capability development goals, development steps, dependencies on other capabilities, organizations, operational activities, and services. Table 5 analyses how our proposed capability models are related to the DoDAF capability models. None of our capability models are able to define a timeline or a plan of capability development. On the other hand, our modeling work was focused on the definition and description of capability state, either present or future, rather than definition of the evolution of the capability, which is an aspect of the capability lifecycle and development program management. Our capability models relate to the DoDAF capability viewpoint models, as shown in Table 5. The most relevant in this respect is UML class diagram CBP elements.

Military CBP was a necessary response to unclear threats, such as peacekeeping or peace enforcement operations, nonnation threats, and asymmetric warfare. These threats are characterized by extreme agility and improvisation in many dimensions of interest. Our aim was to propose capability models that can be used at any level of the defense system hierarchy and at any phase of the capability lifecycle. Therefore, our models support the capability definition and planning of modular and multicapability military units, which are needed for agile and innovative threats. The challenge will be the definition of the environment and enemy capabilities.

Special attention has to be paid making flexible the capability need and system interface definitions and of the architectural designs. This makes it possible to take use of the system innovation, R&D and design by the continuously increasing of technology developers external to military organizations. From the modeling perspective, a comprehensive capability need definition supports rapid review, selection, and implementation of the evolving capability solutions.

TABLE 5 Comparison between DoDAF Capability Viewpoint models and suggested models

DODAF capability viewpoint model	DODAF description	Relation and support to suggested models
CV-1: Vision	Describes a project's visions, goals, objectives, plans, activities, events, conditions, measures, effects (outcomes), and produced objects.	CD describes the effects delivered by the capabilities in the defined conditions, and produced objects required to deliver the capability. Measures for the delivered objects and the effects are included. CM focuses to the definition of the project boundaries and high level description of the produced objects in term of interacting systems. As CD and CM can be used to present arbitrary level of the system hierarchy, they can be used to support the representation of the project visions, goals and objectives. Events and plans which are part of the project management are not covered.
CV-2: Capability Taxonomy	An architectural data repository with definitions of all terms used throughout the architectural data and presentations.	HLDM defines the capability viewpoints and terms. CD defines the hierarchies of the planning elements: the tasks, capabilities and the force elements.
CV-3: Capability Phasing	The planned achievement of capability at different points in time or during specific periods of time. The CV-3 shows the capability phasing in terms of the activities, conditions, desired effects, rules complied with, resource consumption and production, and measures, without regard to the performer and location solutions.	Set of CM and CD's may be used to define different perspectives the capability in different time steps.
CV-4: Capability Dependencies	The dependencies between planned capabilities and the definition of logical groupings of capabilities.	CD defines the hierarchy of the capabilities. Other dependencies between the capabilities are presented by the capabilities' relationships with the tasks or effects, and force elements by CD and DHLDM.
CV-5: Capability to Organizational Development Mapping	The fulfillment of capability requirements shows the planned capability deployment and interconnection for a particular Capability Phase. The CV-5 shows the planned solution for the phase in terms of performers and locations and their associated concepts.	CD defines the relations between the capabilities and force elements which may represent military unit or other organization.
CV-6: Capability to Operational Activities Mapping	A mapping between the capabilities required and the operational activities that those capabilities support.	CD and DHLDM map the capabilities and the operational activities (tasks).
CV-7: Capability to Services Mapping	A mapping between the capabilities and the services that these capabilities enable.	CD and DHLDM map the capabilities and the force elements which deliver the services. Services are not considered as a separate object or a viewpoint.

CM Defense system and its environment – Context model. HLDM Capability viewpoints and terms – High Level Data Model. CD Capability based planning elements – UML class diagram. DHLDM Dynamics of capability degradation – High Level Data model.

The focus of this paper was to provide capability models to support the definition of the capability need and the description of the systems with appropriate capability parameters. Stakeholders are not identified, nor are their power relations studied in this paper beyond this focus. Irrespective of which phase of the capability lifecycle phase the models are applied, it is obvious that in the stakeholder community, there are many worldviews on capability planning and its objectives and decision-making approaches. It is expected that theoretical, analytical and quantitative approaches must be harmonized together with heuristic approaches for problem definition and solving and possibly intuition- and experience-based decision making.

5 | CONCLUSIONS

We have presented a consistent set of CBP models defining the terms and connecting explicitly the existing separate capability viewpoints, and shown that they cover the capability description needs of the capability lifecycle from the definition stage to designing the capability and implementing it as a military unit to the existing defense system. The models can be utilized both for the definition of system and its performance to achieve capability goals, and to assess the systems and changes in their configuration against the capability in a traceable manner. Definitions of the systems and capability may take forms of requirements documentation, architectural descriptions, and mathematical models. To justify the usefulness of this approach we have discussed the logics in our model development by populating the UML model with real-world example parameters, analyzing CBP process needs, and comparing our approach to the DODAF capability viewpoint.

The conceptual model of the defense system in its environment defined the context and object for the CBP using basic system concepts. Our conceptual system model clarifies the defense system structure, and its relation to the environment and the surrounding other actors' systems.

The terms and their relationships in the CBP were defined at the abstract level using a high-level data model. The resulting data model helps the stakeholders in the CBP process communicate. The model shows that each of the terms and elements has interdependencies and therefore none of them can be neglected in the planning process, that is, at least not without reconstruction of the broken links to maintain the model, and the process, coherent.

Our class diagram model defines the pivotal planning elements in CBP, including a minimum set of attributes, operations and relationships. Due to the generic approach of the model, it can be utilized at any level of the defense system hierarchy and to define one's own, partner, and enemy. The UML class diagram defined the planning elements in capability planning, operational planning and operations, or in the management of existing capabilities with appropriate instances of the classes. As a result, the model can be applied through the capability lifecycle. Consequently, if the model is implemented as an information system, then the same data model could be used through the capability lifecycle. Furthermore, this model will allow the planning and managing of all aspects of the capabilities with the same software tools or at least help in building interoperable software. As a demonstration, the model was applied to a brigade formation with real-life data.

The representation of the degrading capability connects the previous models to the operational context and the problem definition in terms of the effects caused by the enemy. This representation establishes a platform for the further modeling and analysis of the defense system dynamics, which is the logical next step in the inquiry of the behavior of the defense system and the nature of the capability.

Further research is suggested for the application of mathematical models to define the defense system and capability to suggest optimization methods for solving real-life combinations of subsystems.

DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

ORCID

Jouni Koivisto https://orcid.org/0000-0002-1936-3288

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AUTHOR BIOGRAPHIES

Jouni Koivisto received his BSc in mechanical engineering from the Tampere Institute of Technology in 1997, MSc in automation technology from the Tampere University of Technology in 2006, MSc in systems engineering for defence from the Cranfield University, Shrivenham, UK, in 2008. From 2008 to 2015 he was Senior Engineer with Defence Command Finland, where his work focused on capability engineering and development of respective tools and methods in various levels of planning. Since 2015, he has been a Research Manager with the Information Technology Division, and since 2018, a Research Director, Finnish Defence Research Agency, Riihimäki. His current research interests are systems thinking, modeling, optimization, capability management, and technology forecasting.

Risto Ritala received his master's and doctoral degrees in engineering physics from Helsinki University of Technology in 1981 and 1986, respectively. From 2003 to 2021 he has been a Professor in measurement information technology at the Faculty of Engineering and Natural Sciences at Tampere University. His research interests are optimal sensing and related estimation, prediction, data analysis, modeling, system dynamics, and optimal control.

Matti Vilkko received the MSc degree in electrical engineering in 1989, and the Dr. Tech degree in automation engineering in 1999, from the Tampere University of Technology, Tampere, Finland. From 2000 to 2003, he held research and development management positions with Patria Ailon Inc. and Ailocom Inc. In 2003, he became a Senior Researcher and in 2010 became a Professor in process control at the Faculty of Engineering and Natural Sciences at Tampere University. His current research interest is in the areas of process control, modeling, simulation, and system identification.

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