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Enterprise Architecture for Maritime Security using the NATO Architecture Framework and the Key Performance Indicators concept

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Abstract

The NATO Architecture Framework (NAF) metamodel incorporates metrics, measures, and indicators, using the Unified Architecture Framework Domain Metamodel to more robustly establish measurement goals. However, the implementation of Key Performance Indicators (KPI) is not utilised correctly, unlike in some current Enterprise Architecture Frameworks (EAF).

A well-designed set of KPIs integrated into NAF could set clear targets for collaborative entities, define milestones to measure progress, and generate actionable insights that facilitate informed decision-making at the organisational level. KPIs can also be linked to EA artefacts and methodologies, creating a robust framework for evaluating the alignment between architectural components and strategic goals.

This paper aims to develop an EA with KPIs for maritime security and to validate the new NAF metamodel's ability to incorporate them. In this sense, a suitable KPI formulation to integrate into an EA is the best way to measure goal performance over time, facilitate benchmarking, and mitigate risk.

Keywords:

Enterprise Architecture, Enterprise Architecture Framework, Key Performance Indicators, Maritime Security, NATO Architecture Framework.

1. Introduction

This paper aims to highlight the methodology, viewpoints, and NAF metamodel, the integration of KPIs within the NAF, and to propose an improvement to the process using a structural and hierarchical model. It also aims to develop the EA for maritime security using the NAF, incorporating KPIs into the metamodel, making a significant contribution to addressing this issue globally.

1.1. Background

The KPIs can be defined by the target metric used to facilitate assessment and management; that is, this target, correlated with a value, must be assigned a metric before it can be used as an indicator (Weber & Thomas, 2005, pp. 3-6). The implementation of KPIs in some Enterprise Architecture Framework (EAF) and, subsequently, in EA is already underway; however, the NAF has not yet adequately incorporated this doctrine. Therefore, it remains essential to locate, analyse, synthesise, and interpret research on the NAF methodology and perspectives, its metamodel, and the need to integrate KPIs (Kaganski, Majak, Karjust, & Toompalu, 2017).

Conversely, the maritime security model remains insufficiently optimised and inefficient at exchanging information among operational centres worldwide, despite the presence of multiple threats and risks in the maritime domain. Consequently, establishing an EA for maritime security should be a realistic goal. Additionally, including KPIs in the NAF metamodel could help solve the problem presented.

1.2. Purpose

The development of an EA for maritime security using the NAF with KPIs in its own metamodel aims to demonstrate that creating an EA dedicated to maritime security with KPIs is the best solution because numerous organisations, entities, and agencies are committed to maritime security at both local and regional levels and do not operate together in a fully interoperable and coordinated manner.

1.3. Research Objectives

The three goals of this paper are: (i) verify the NAF concept and processes for an EA; (ii) confirm the integration of principles and KPIs within the NAF metamodel; and (iii) develop an EA for maritime security.

1.4. Structure

The paper's structure includes the Systematic Literature Review (SLR) of the NAF background, the main architectural processes, the architecture framework, activities and viewpoints, the grid representation of the NAF, and the NAF metamodel. Similarly, it incorporates the KPI principles and their integration into the NAF metamodel. The paper concludes by developing an EA for maritime security. Following this, an SLR will be conducted on NAF and related issues.

2. Systematic Literature Review

In this research, we aim to resolve the NAF doctrine by focusing on its methodology, viewpoints, and metamodel, and by addressing the KPI process, its principles, and their integration into the NAF. The study culminates in a KPI proposal tailored to the security and defence domain, specifically for maritime security. The paper concludes with an analysis of the results, a discussion, and a conclusive synthesis (Pollock & Berge, 2018).

However, it remains essential to locate, analyse, synthesise, and interpret research on the NAF methodology and viewpoints, its metamodel, and the need for KPI integration. This contributes to research, knowledge development, and the provision of solutions, and brings about environmental changes and/or transformations in the study area. It should also be noted that no limitations are anticipated for the research in this paper (Manfredi & Tirone, 2018).

2.1. Design

In terms of methodology, the research primarily focused on theoretical aspects, emphasising the interdependence between the NAF and the importance of using KPIs to establish an EA for military security and defence operations. In this context, to understand the problem and conduct the research, the aim was to apply Design Science Research (DSR) procedures throughout its cycle to identify the issue and subsequently provide solutions (Brocke, Hevner, & Maedche, 2020).

Hence, through DSR, awareness of the problem was sought, revealing the absence of an EA for maritime security at the local, regional, and global levels, which could be analysed simultaneously to verify whether strategic objectives have been achieved. To this end, incorporating KPIs into the existing EAF metamodel is fundamental. Thus, the identified suggestion involves building an EA on maritime security, applicable locally, regionally, and even globally, using the NAF, which is considered appropriate for the security and defence domain, thereby creating an artefact for the maritime domain. To achieve performance measures, KPIs are used. Regarding results, in addition to creating the EA for maritime security, the incorporation of KPIs into the NAF metamodel was also analysed.

2.2. Method

Thus, moving on to the stages of the SRL, the study method used as a reference follows the guidelines for conducting a review (Kitchenham & Charters, 2007). SRL is a crucial step in advancing knowledge, especially in social sciences (Durach, Kembro, & Wieland, 2017). It helps to understand social sciences more profoundly and to identify them more effectively for exploration. SLR is defined as the process of identifying, evaluating, and interpreting research evidence to answer a Research Question (RQ) (Kitchenham, et al., 2009). The method and style of the review are informed by the studies (Zainal, et al., 2023); (Reda & Zellou, 2023).

2.3. SLR research question

This research aims to describe the review structure by defining the SLR RQ and outlining a search process for relevant keywords across multiple scientific databases. Next, two RQ related to the SLR investigation are described in Table 1, along with the respective hypotheses.

Table 1 – SRL RQ

No	SLR RQ	Objective
RQ1	How can KPIs be formulated to monitor and evaluate the EA and the security and defence domain?	Check the number of studies on the use of KPIs in NAF to determine whether this topic has been adequately studied to build an EA for maritime security using NAF.
Hypothesis	The incorporation of KPIs into the NAF metamodel is feasible, enabling measurement of various dimensions and parameters across the EA, security, and defence domains.	
RQ2	What is the result of validating the NAF proposal applied to the EA and the maritime security domain?	
Hypothesis	The introduction of KPIs into the NAF metamodel allows for improved EA governance and maritime security management.	

2.4. Search process

Therefore, the research process for SLR focuses on identifying various digital scientific sources and databases, such as scientific journal articles and conference proceedings. The sources used to support the SLR search include

well-known digital scientific databases, such as Scopus, Google Scholar, ScienceDirect (Elsevier), Springer, IEEE Xplore, and ACM Digital Library, as well as military databases like NATO. Boolean connectors and temporal and geographical delimitations were applied (Andersen & Carugati, 2014).

The terminology used in RQ1 is highly diverse, so it requires using synonyms or a variety of keywords during the research process. Search keywords help find relevant information in scientific studies and articles. Therefore, in this literature search, for RQ1, keywords such as "KPI use in NAF", "NAF performance gaps", "extension of the NAF metamodel to include KPI", "EA using NAF", or even "NATO Architecture Framework" are utilised to locate the most relevant research aligned with the expected target literature.

Notwithstanding, for RQ2, keywords such as "EA for the maritime security domain", "EA for maritime security using the NAF", "KPI design for the maritime security domain", "construction of NAF viewpoints for an EA", or even "building NAF viewpoints for a maritime security EA using KPIs in its metamodel" are utilized to locate the most relevant research aligned with the expected target literature. Consequently, a search strategy was employed using a database query and keyword filters, covering October 2018 to June 2025.

2.5. Review conduction

The review rules for executing SLR concerning its implementation structure are outlined. From the exclusion process based on inclusion and exclusion criteria, the selected studies are generated through the study selection procedure, namely (Khairina, Purwanto, & Nugraheni, 2024):

- Inclusion criteria: (i) studies in scientific journals and proceedings of international conferences on EA for security and defence; (ii) studies in scientific journals and proceedings of international conferences on EA for maritime security; (iii) studies in scientific journals and proceedings of international conferences on NAF; (iv) studies in scientific journals and proceedings of international conferences on the use of KPIs; (v) studies focused on research areas related to the incorporation of KPIs in EAF; (vi) studies in the research area from 2018 onwards, mainly from NATO on performance measures in NAF; (vii) studies focused on the model/method/approach used to incorporate KPIs in the NAF metamodel; (viii) studies related to the use of KPIs in EAF; (ix) articles mentioning NAF and KPI use versus documents addressing only other EAF.
- Exclusion criteria: (i) studies unrelated to the research area of NAF and KPI; (ii) short articles, posters, and similar formats; (iii) studies not addressing the RQ; (iv) studies that do not mention NAF or Unified Architecture Framework (UAF); (v) publications before version 4 of the NAF (2018); (vi) duplicate studies.

Conversely, the SRL selection process was guided by the principles of the model known as Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), covering everything from justifying the specific RQ to presenting a study selection flowchart, inclusion/exclusion criteria, data classification and synthesis, and the critical assessment of the methodological quality of the chosen articles (PRISMA, 2020).

Alongside the PRISMA methodology, the Population, Intervention, Comparison, and Outcome (PICO) framework was also employed, helping researchers identify the key components of a study, including the target population, the intervention being studied, a comparison group (if relevant), and the expected outcomes (CASP, 2025).

Therefore, the articles and reports presented identify publications related to the research topic, making it clear that the electronic sources disseminate a range of articles, reports, and studies. Still, none are fully dedicated to extending the NAF metamodel to incorporate KPIs. Additionally, an analysis was conducted, encompassing studies identified by main themes, resulting in a critical review, namely:

- Theme A: defining a metamodel for KPIs in NAFv4, based on studies detailing SMM, Unified Architecture Framework Domain Model (UAF DMM), and MODEM extensions.
- Theme B: new viewpoints or dashboard proposals for the NAF, within the scope of the work that suggests creating a "HQ Dashboard Viewpoint" or "KPI Library".
- Theme C: case studies and tools, to illustrate cases that implemented measurement environments in NAFv4.
- Theme D: performance evaluation in real-world scenarios, based on articles that measured effectiveness after EA implementation.

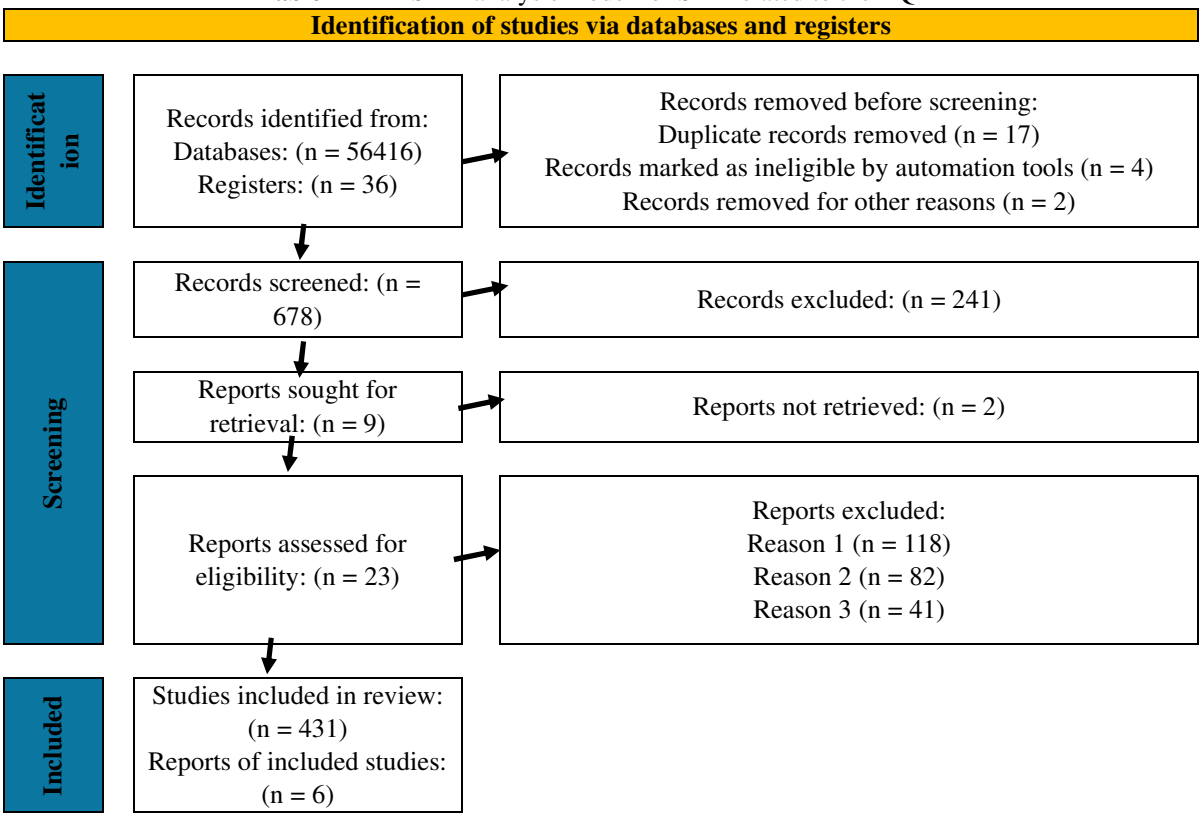
This analysis aims to identify: (i) author/year; (ii) source (journal, article, or conference); (iii) objective of the study; (iv) EAF addressed (NAFv4, DoDAF, MoDAF, UAF, etc.); (v) proposed primary metrics or KPIs; (vi) type

of evidence (theoretical, simulation, case study); (vii) limitations. Therefore, this analysis enabled us to quickly visualise which articles proposed metamodel extensions, assessed dashboards, or merely listed gaps without suggesting a solution.

This approach aims not only to document the current state of the art in NAFv4 metrics but also to make an original contribution, including a structured overview of gaps, a taxonomy of approaches, and a clear roadmap for future research and tool development. Hence, this PRISMA flowchart aims to map the number of records identified, included, and excluded, along with the reasons for exclusions, for the SLR (Tables 2 and 3), namely:

- Identification: (i) counted the total number of records found in each item database; (ii) conducted searches in digital scientific database sources using keywords; (iii) performed study exclusions based on pre-determined exclusion criteria.
- Screening: (i) removing duplicates and screening titles/abstracts, with a record of how many were excluded and clear justification; (ii) identifying study articles that cannot be found or obtained; (iii) making exceptions for irrelevant studies based on the identification of title, abstract, and/or full text content; (iv) making exceptions for studies that do not specify the model, method, or approach used.
- Eligibility: the full texts of the remaining articles were analysed, noting the number of articles excluded at this stage and their reasons.
- Inclusion: (i) identified the final number of studies included in the qualitative synthesis; (ii) re-evaluated the study results; (iii) primary studies have been obtained.

Table 2 – PRISMA analysis model for SRL related to the RQ1



Source: (PRISMA, 2020)

Moreover, a considerable number of studies address metrics and KPIs in the context of NAFv4. Still, very few refer to the possible extension of the NAF metamodel to incorporate KPIs. Some mention the need to incorporate KPIs into the NAF. Still, minimal attention is given to the why or how of incorporating KPIs into the NAF metamodel. Therefore, the number of scientific articles published in journals and/or conferences, as well as studies, from 2018 (due to the enactment of NAFv4) to August 2025, is presented using the defined keywords (Figure 1).

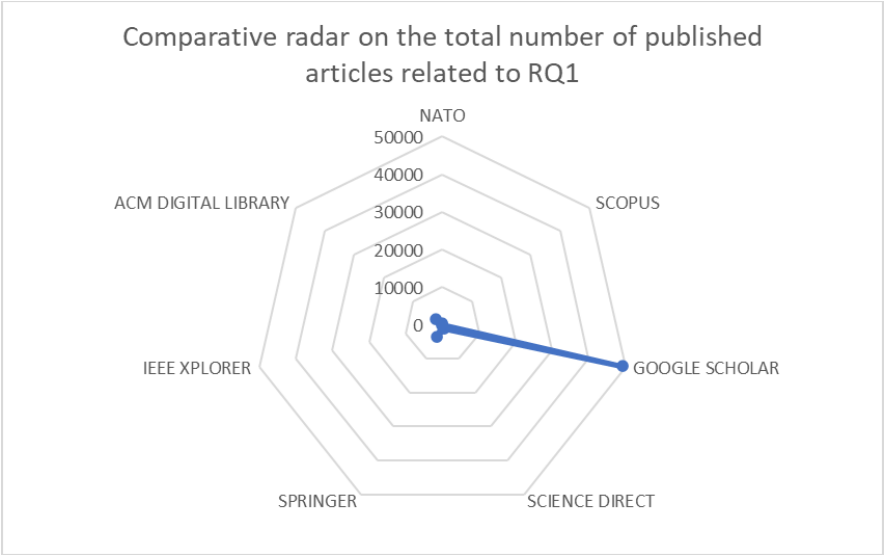


Figure 1 – Comparative radar chart for the number of articles and studies published in digital sources from 2018 to 2025 related to RQ1

Regarding RQ2, the following Table shows the PRISMA flowchart, namely:

Table 3 – PRISMA analysis model for SRL related to the RQ2

Identification of studies via databases and registers		
Identification	Records identified from: Databases: (n = 50096) Registers: (n = 8)	Records removed before screening: Duplicate records removed (n = 37) Records marked as ineligible by automation tools (n = 8) Records removed for other reasons (n = 2)
Screening	Records screened: (n = 1345)	Records excluded: (n = 344)
	Reports sought for retrieval: (n = 7)	Reports not retrieved: (n = 9)
	Reports assessed for eligibility: (n = 22)	Reports excluded: Reason 1 (n = 127) Reason 2 (n = 114) Reason 3 (n = 103)
Included	Studies included in review: (n = 985) Reports of included studies: (n = 16)	

Source: (PRISMA, 2020)

Previously, for RQ2, the analysis revealed that the literature covered all the keywords. However, despite extensive literature on EA and KPI frameworks, there is no clear proposal for an EA for maritime security, nor is there a framework for designing KPIs. Additionally, there is limited literature on incorporating KPIs into the NAF metamodel. This implies a lack of literature on constructing viewpoints for the NAF using KPIs. Thus, the number of scientific articles published in journals and/or conferences, as well as studies, from 2018 to August 2025, is presented using defined keywords (Figure 2).

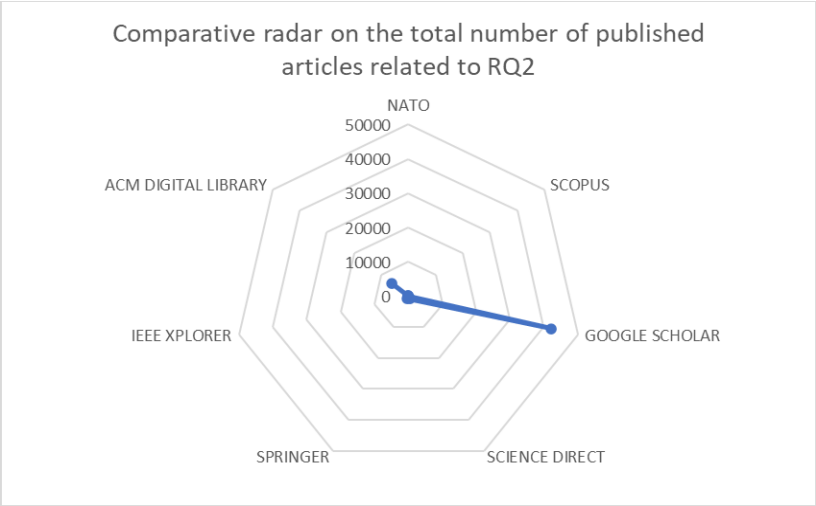


Figure 2 – Comparative radar chart for the number of articles and studies published in digital sources from 2018 to 2025 related to RQ2

The considerable decrease in the number of identified articles, compared with the number of screened records presented in both RQs, was due to an analysis that selected only articles related to the paper's topic.

3. Building an Enterprise Architecture for Maritime Security

For the central part of the article, we intend to review the context of the NAF, propose a hierarchical structure for KPI design, provide an example of a KPI for maritime security, and conclude by constructing an EA for maritime security.

3.1. NATO Architecture Framework background

The NAF methodology explains the approach and environment in which architecture addresses activities and is governed, managed, defined, and evaluated. Each organisation must adapt the methodology to relevant processes, methods, means, and issues. NAF enhances Situational Awareness and Situational Understanding (SASU) through information fusion, integration, and intelligent processing of multiple sources, as well as through digitalisation and process automation, thereby reducing human intervention (NATO, 2026, pp. 24-25). The aim of using the NAF methodology is to compare international and national instruments, thereby providing a basis for the deductive construction of the EA. This method addresses the active problem, expectations, and practical solutions, following all steps or stages outlined in the NAF (Figure 3).

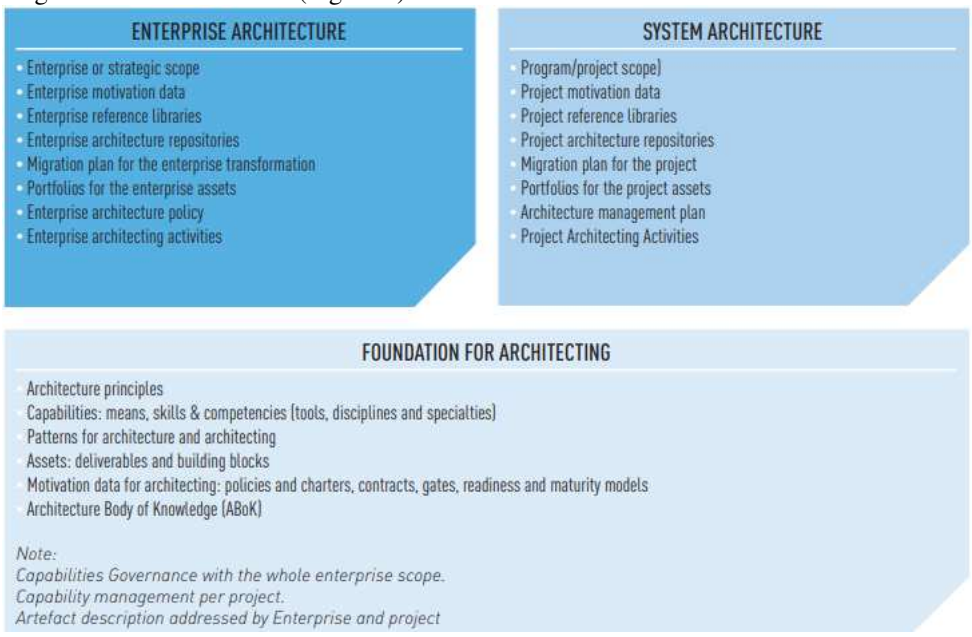


Figure 3 – NAF version 4 methodology
Source: (NATO, 2026, p. 25)

More than ever, this EAF served as the reference for defining an EA applied to the security and defence domain. This process is based on a comprehensive approach depending on the environment and how activities are conduct, managed, defined, and evaluated, going through the processes, methods, and means applicable to each organization, creating a system or product according to existing resources, requirements, and meeting the needs of various stakeholders to develop an EA, through four possible types, namely: (i) Business Architecture; (ii) Information Architecture; (iii) Application Architecture; and (iv) Technology Architecture (NATO, 2026, pp. 25-28).

To simplify the process, four standardised architectural styles are recognised. These styles help determine the approach to adopt, set expectations for what can be achieved, clarify what is involved, and aid understanding of how value is delivered to the organisation. The four architectural styles identified are as follows: (i) authoritarian; (ii) directive; (iii) coordinating; and (iv) support (NATO, 2026, p. 28).

3.2. Main architectural processes

ISO/IEC/IEEE 15288:2013 (ISO, 2023) describes the process, activities, and tasks related to architecture, utilising five methods that can be performed by different organisations and projects within a company. This process description aligns closely with ISO/IEC/IEEE 42020:2019 (ISO, 2019a).

The first process is architecture governance, which relates to EA consistency. It encompasses the strategic activities that guide the architecture in alignment with the company's strategies and objectives. Key architectural governance activities comprise: (i) establishing the capability for architectural governance; (ii) defining desired strategic outcomes for the architecture portfolio; (iii) assessing the coherence of architecture roadmaps towards the intended results; (iv) guiding the architecture portfolio and associated activities; (v) monitoring the company's architecture portfolio and related activities to ensure adherence to governance guidelines; and (vi) deciding on necessary corrective actions and repeating the process (NATO, 2026, pp. 28-29).

The second process involves managing an EA. It is a process for planning, executing, and monitoring architecture throughout its lifecycle. The aim is to develop architectures that are aligned with corporate governance direction and stakeholder expectations. These activities include: (i) establishing management capacity for one or more architectures and related activities; (ii) creating plans to carry out architectural management activities under architectural governance directions; (iii) providing guidance and direction for architectural activities; (iv) monitoring and evaluating the architecture development with management guidance; and (v) deciding on necessary corrective actions and iterating (NATO, 2026, p. 29).

Conversely, the architecture description process aims to follow ISO/IEC/IEEE 42010:2022 (ISO, 2022b). The main activities identified are: (i) analysing the problem situation (purpose and goals); (ii) identifying stakeholders, their concerns and needs; (iii) formalizing and classifying the main requirements based on the needs collected; (iv) identifying potential solutions; (v) identifying architectural viewpoints according to stakeholders' concerns; (vi) developing architectural models and visualizations from these viewpoints; (vii) providing justification for potential solutions concerning requirements and motivation, in particular, ensuring their traceability to motivation data; (viii) reviewing the architecture during construction with stakeholders and obtaining their approval; and (ix) establishing relationships between architectures, design and other downstream activities (NATO, 2026, p. 30).

Regarding the architecture assessment, the process aims to follow ISO/IEC/IEEE 42020:2019 (ISO, 2019a) and ISO/IEC/IEEE 42030:2019 (ISO, 2019b). These standards specify architectural assessment activities, including: (i) defining the purpose, design, and assessment goals; (ii) identifying the stakeholders of the architecture assessment and their concerns or questions; (iii) establishing evaluation criteria (based on stakeholders' concerns/questions) with their relative importance (priorities, weights, etc.); (iv) selecting techniques, methods, and tools to carry out the assessment; (v) evaluating the architecture; (vi) collecting and understanding the necessary information about implemented metrics; and (vii) forming conclusions and recommendations (NATO, 2026, p. 30).

In another aspect, architecture requires an activation process to develop, maintain, and enhance the capabilities, services, and resources needed to establish and sustain it. This may involve acquiring or developing these capabilities, services, and resources as required. Capacity facilitators include, among other elements, (i) procedures, methods, and tools; (ii) structures and architectural viewpoints; (iii) work product models; (iv) decision support systems and storage; and (v) configuration management and reference models. Service enablers include, among other components: (i) infrastructure and technologies; and (ii) qualified personnel and automation agents. Meanwhile, resource enablers comprise: (i) architecture repository, library, and registry; (ii) communication

channels and mechanisms; (iii) human and technical resources; and (iv) licenses for tools and methods (NATO, 2026, pp. 30-31).

Regarding the architecture lifecycle, it is understood that an architecture is a living entity that guides lifecycle processes, as outlined in ISO/IEC/IEEE 15288:2023 (ISO, 2023) and ISO 12207:2017 (ISO, 2017). Architecture has its lifecycle—from inception to conclusion—which guides the lifecycle of the architected entity. The processes (or activities) support the subject of interest throughout its lifecycle, that is, any activity necessary to make this subject workable. When directly associated with a system, architecture lifecycle maps are tied to the entire system lifecycle, from conception to retirement (NATO, 2026, p. 31).

3.3. Grid representation of the NATO Architecture Framework

The NAF network representation is a standardised two-dimensional classification scheme for NAF viewpoints that is the basis for any NAF-compatible architecture effort. However, the selection of viewpoints must be tailored to the specific architectural endeavour (i.e., proper to the viewpoints that need to be identified in the grid) (Figure 4) (NATO, 2026, p. 79).



Figure 4 – Simplified NAF metamodel terms
Source: (NATO, 2026, p. 79)

The grid representation illustrates the NAF viewpoint scheme, organised by concern subject (rows) and concern aspect (columns). Additionally, it contains relevant information for the architecture to be developed, supporting the analysis process and optimisation/resource dependence, thus serving as the foundation for a coherent and effective architecture in accordance with its own stages (taxonomy, structure, connectivity, behaviour, information, constraints and roadmap) (NATO, 2026, p. 79).

3.4. Principles of Key Performance Indicators

Using KPIs would enable the identification of indicators for assessing an EA designed to mitigate risks and improve safety and security conditions. The generic evaluation criteria and KPIs for an EA will depend on the specific evaluation goals, the application phases of the NAF methodology, and the viewpoints from which they will be used. However, some of the strategic-level criteria and meta-indicators that could be used in EA assessment could include (Khayami, 2011):

- Alignment with organisational goals: This criterion assesses the degree of EA alignment with the organisation's goals. Indicators that can be used include the percentage of organisational aims supported by EA and the percentage of EA components aligned with organisational goals.
- Effectiveness evaluates the EA's ability to achieve its intended goal. Indicators may include the number of successful EA component implementations, the percentage of users who are satisfied with the EA, and the time required to implement changes into the EA.
- Efficiency evaluates the degree of EA efficiency in terms of resource use. Indicators may include implementation cost, EA maintenance cost, time required to implement EA changes, and the percentage of EA components reused across projects.
- Security: assesses the degree to which EA supports the organisation's security needs. Indicators may include the number of security breaches or incidents, the percentage of security requirements that the EA supports, and the time required to implement security- and defence-related changes to the EA.
- Agility assesses the EA's degree of flexibility and its ability to adapt to changing organisational needs. Indicators of agility may include the time required to implement EA changes, the percentage of EA components that can be easily modified, and the number of successful EA changes.

Other indicators related to these, or other criteria, will depend on the specific EA to be built. By proposing KPIs, NAF can comprehensively assess EA effectiveness across contexts and domains. In addition to the meta-indicators, it must be considered that the EA must support the set generation of specific indicators to the domain, namely (Domínguez, Pérez, Rubio, & Zapata, 2019):

- Alignment with domain goals: the extent to which the systems recommended by EA align with the organisation's aims and goals for the security and defence domain.
- Functional completeness: the extent to which systems respond to security and defence functional requirements.
- Technical completeness: the extent to which systems address the technical requirements for domain protection, such as security and interoperability.
- Adaptability: the extent to which systems can adapt to security and defence changes, such as technological changes or new security threats.
- Integration: the extent to which systems can integrate with other systems and technologies used in the organisation and partners.
- EA cost-effectiveness: cost commitment vs. system effectiveness in development, implementation, and maintenance.
- Usability: the extent to which systems are easy to understand, use and support.
- Performance: system performance in speed, scalability, and reliability.
- Security: Systems effectively protect against security and defence threats and vulnerabilities.
- Stakeholder satisfaction: the degree of satisfaction among the main stakeholders, such as end users, top management, and external partners.

On another level, KPIs development involves related concepts and relationships to acquire a new dynamic. These are measurable values that provide insight into an entity's performance and progress. Following ISO/IEC 25000:2014 (Systems and software engineering — Systems and software Quality Requirements and Evaluation (SQuaRE) — Guide to SQuaRE) (ISO, 2014), to evaluate the EA conformity artefacts with the best NAF practices, some of the main characteristics required of KPIs include (Noetzel, 2018):

- Relevance: being aligned with the organisation’s goals and aims.
- Measurability: measurable and has a defined method for collecting data.
- Clarity: models’ degrees about whether they are clear, transparent, and understandable, both for partner architects and stakeholders.
- Comparability: can be compared over time or between similar organisations.
- Opportunity: be updated and communicated regularly to ensure superior information and prompt decision-making.
- Actionable: offering actionability that can be used to make informed decisions and drive improvements.
- Balance: provide a balanced performance view across multiple dimensions.
- Credibility: to what extent the data is dependable and for what EA should stand.
- Currentness: the extent to which the data is ready and updated.
- Accessibility: the extent to which users with distinctive characteristics can use data to achieve a defined goal.

- Confidentiality: the extent to which data is protected against unauthorised access.
- Efficiency: the extent to which data processes (i.e., storage, filtering, sharing) can be applied.
- Precision: the extent to which random errors are described in the data.
- Understandability: the extent to which users with distinct characteristics understand the data.
- Availability: the extent to which the data is accessible and operable, so it must be used.
- Portability: the extent to which data can be transferred from one application to another.
- Recoverability: the extent to which data, after a failure or error, can be recovered and returned to its original state.
- Completeness: the degree to which EA models cover relevant aspects of the organisation, including domain, information, and technology.
- Consistency is the degree of solidity of EA models in all aspects and layers, without redundancies, inconsistencies, or conflicts.
- Reusability: the degree to which EA models can be easily reused and expanded by other architects in the organisation.
- Traceability: the degree to which models can be investigated until their primary causes are discovered, namely the organisation's goals and aims and the initially defined requirements.
- Accuracy: the degree to which models accurately represent the organisation's current and future goals is regularly updated to reflect changes.
- Usability: the degree to which models can be used to support decision-making processes at a strategic and operational level.
- Flexibility (adaptability): the degree to which models can adapt to changing organisational needs, specific organisational requirements, and emerging technologies while maintaining their integrity and coherence.
- Alignment: degree to models is aligned with the organisational strategy, goals, and aims and supports their reuse.
- Interoperability is the degree to which various parts of EA models can communicate and share information. It can be calculated as the interface percentage or the number of integration points that are compatible with each other in EA models.
- Integration: the degree to which EA models can be integrated with other systems or platforms. It can be calculated as the percentage of integration points in EA models compatible with external systems or platforms.
- Conformity: the degree to which EA complies with industry interoperability standards, the NAF metamodel, and its principles. It can be calculated as the percentage of EA model components that meet industry interoperability standards.
- System complexity: the degree to which EA models simplify system complexity and improve interoperability. It can be calculated as the percentage reduction in system complexity achieved by EA models.
- Data sharing: the degree to which EA models aid data sharing between various parts of the organisation can be calculated as the percentage of data elements in EA models shared between distinct parts of the organisation.

Consequently, there is a vast set of international standards relating to the creation of KPIs, particularly in software engineering, which is shown below, namely:

- ISO/IEC 25021:2012 - Systems and software engineering — SQuaRE — Quality measure elements (ISO, 2012).
- ISO/IEC 25022:2016 - Systems and software engineering — SQuaRE — Measurement of quality in use (ISO, 2016a).
- ISO/IEC 25023:2016 - Systems and software engineering — SQuaRE — Measurement of system and software product quality (ISO, 2016b).
- ISO 8000-63:2019 - Data quality — Part 63: Data quality management: Process measurement (ISO, 2019c).
- Structured Metrics Meta-Model (OMG, 2017).

After reviewing the principles of KPIs, we will analyse how KPIs are integrated into the NAF metamodel.

3.5. Integration of Key Performance Indicators into the NATO Architecture Framework

The aim is to verify the feasibility of integrating KPIs into the NAF metamodel using the proposed structural and hierarchical model applicable to the security and defence domain (Figure 5), the concepts of which are explained in the annex. This also aims to provide an example of KPIs for an EA. It is emphasised that the developed structure is designed to consolidate and integrate the frameworks of the Business Motivation Model (BMM), the Balanced Scorecard (BSC), the stages of EA modelling, the KPI development process, and insights from the NAF. The structure reflects an extended process that spans the development of an alternative EA and the establishment of essential KPIs to verify the defined goals and metrics. The fundamental concepts for building the hierarchical KPI model are explained in the Appendix.

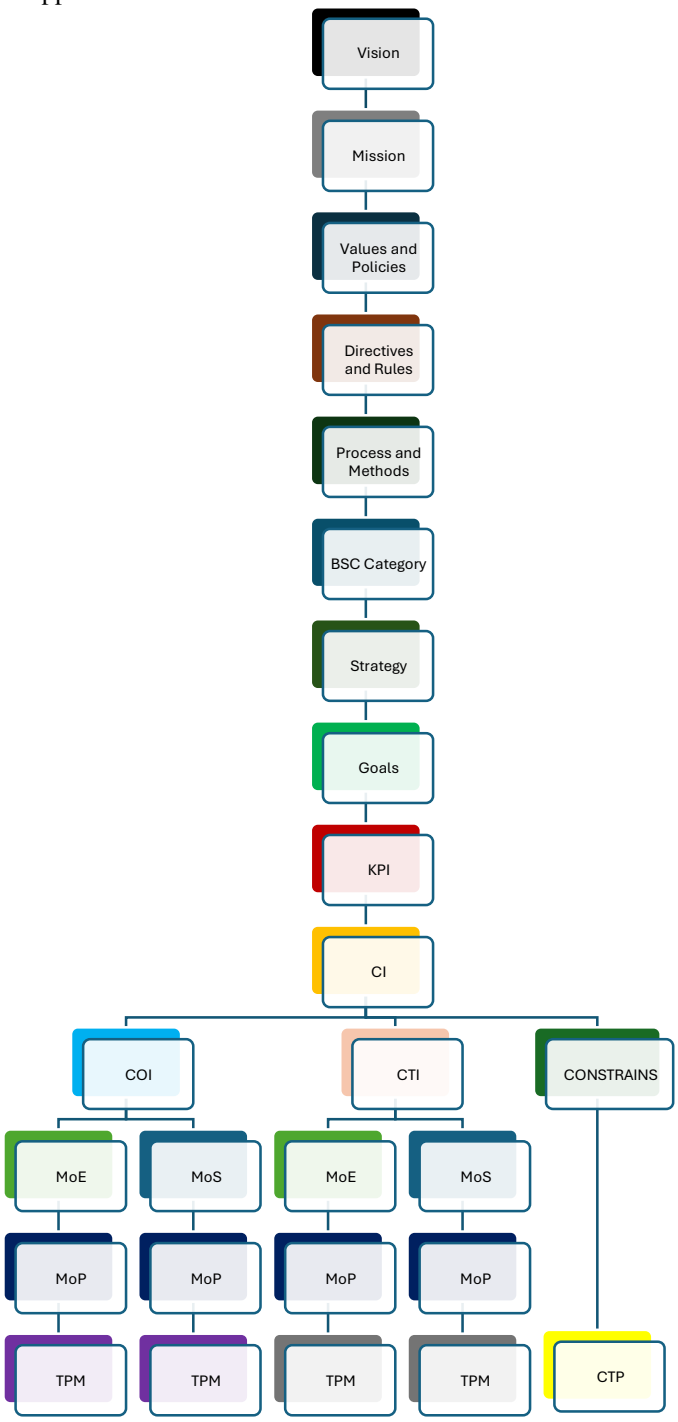


Figure 5 – Structure proposal to formulate KPIs

Source: adapted from (Ryan, 2014) (Krishnapillai, 2009) (Kaganski, Majak, Karjust, & Toompalu, 2017) (Cortes, 2014) (Zdravkovic & Stirna, 2019, p. 1129) (Gröschel & Roth-Dietrich, 2016) (Yu, Strohmaier, & Deng, 2006) (Stelzer, 2010) (NATO, 2026)

On the other hand, it was also verified that the NAF, in its latest version 4, states that the architecture evaluation process includes the use of metrics, measures, and indicators applicable to certain gridlines within the NAF. Using the current NAF metamodel, it is worth noting that it has not been updated by the UAF DMM latest update, from 2023 (OMG, 2023), as the NATO document refers to guidelines for modelling the UAF DMM from 2019 (NATO, 2019).

Thus, it is intended to transform each NAF viewpoint, particularly those that include metrics, measures, and indicators, by analogy with the structural and hierarchical model proposed and the latest version of the UAF DMM. The following information can be inferred from the analysis of the NAF and the proposed model. The justification for this analogy to be made is found in Appendix A, making it possible to create a correlation with the concepts presented:

- Use of Vision Statement: this applies to the vision, mission, and political values, and is often referred to as the first strategic phase.
- Use of Statement of Goal: this includes directives and rules, processes, and methods, BSC categories, strategy, and goals, and is known as the second strategic phase.
- Status Indicator Usage: this relates to KPIs.
- Use of Measure in Context: this pertains to the Critical Issues (CI).
- Use of Measures: this pertains to the COI.
- Use of Measure Category: this relates to the Moe.
- Use of MoE: this involves the MoE and Mos.
- Use of MoP: this involves the Mop.
- After using MoP, can utilize the TPM.

Per this correlation and the latest UAF DMM update, there are measurement parameters that include the following (OMG, 2023): (i) ActualMeasurement; (ii) ActualMeasurementSet; (iii) ActualPropertySet; (iv) ActualService; (v) ActualState; (vi) Capability; (vii) Competence; (viii) Condition; (ix) MeasurableElement; (x) Measurement; (xi) MeasurementSet; (xii) PropertySet; (xiii) ProvidedServiceLevel; (xiv) RequiredServiceLevel; (xv) Resource; (xvi) Service; (xvii) ServiceInterface; and (xviii) StrategicPhase.

Furthermore, the document states that measurements support analysis and can include KPIs such as MoE and TPM (OMG, 2023). In particular, the MeasurableElement parameter, defined as a property of an element that represents something in the physical world and is expressed in units of measurement, is associated with a series of other components, reflecting the UAF DMM's focus on measures, metrics, and indicators. However, the concept of KPIs and the proposed structural and hierarchical model have not yet been adequately implemented (Figure 6).

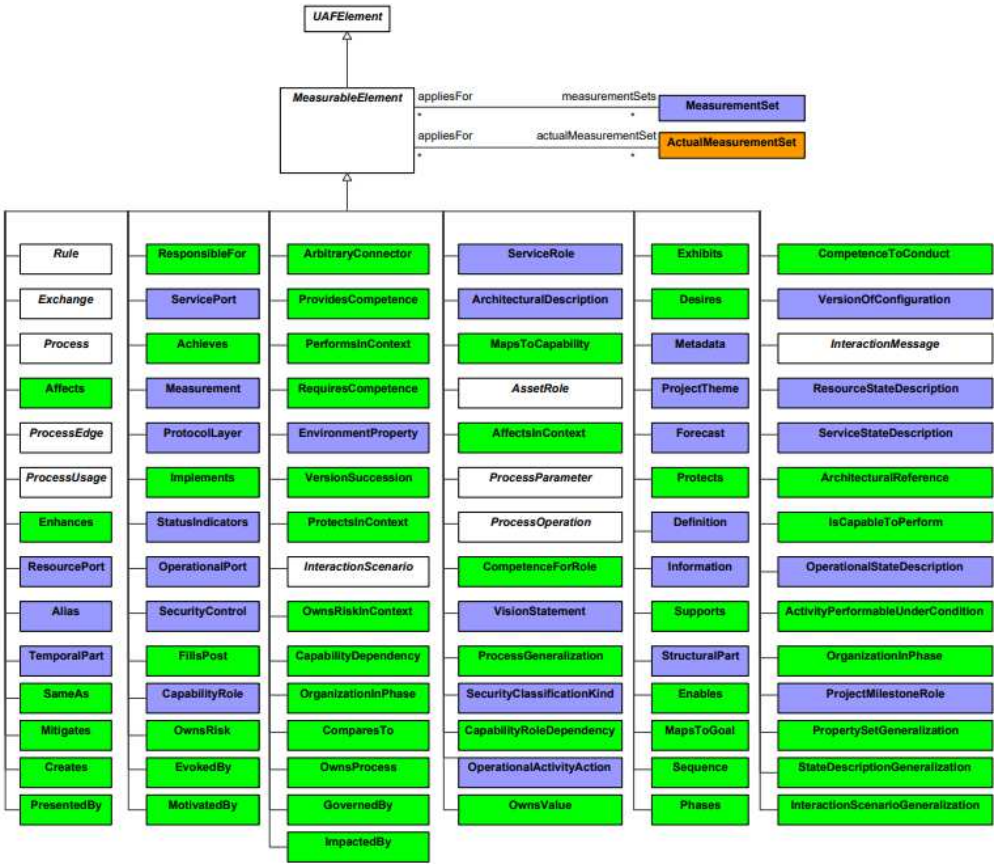


Figure 6 – MeasurableElement Parameter Elements
Source: (OMG, 2023)

An example is the Architecture Meta-Data gridline, namely Architecture Status (A5), which highlights the need to implement the Status Indicator parameters. Therefore, following the same approach, in column A5, there will be (Figure 7).

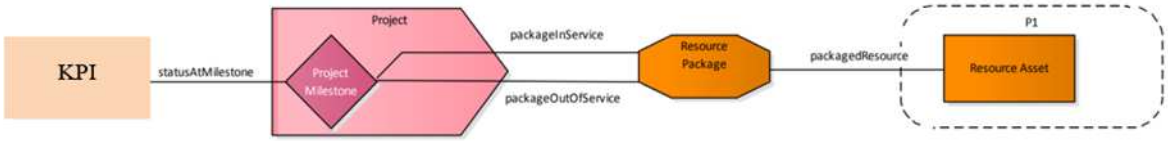


Figure 7 – Optional use of the Status Indicator parameter in Pr
Source: adapted from (NATO, 2019, p. 85)

The NAF can be improved by applying the KPI concept and using the structural and hierarchical model proposed in this research. If the NAF did not implement the KPIs in its metamodel, the EA status cannot be adequately verified. Therefore, the expected results cannot be achieved. Hence, generic KPIs can be formulated without the obligation always to fill all fields, but rather by following the chosen structure. The formulation of generic KPIs was adapted to an EA framework for security and defence, which is entirely associated with the NAF doctrine. Therefore, the generic KPIs can be included in an updated version of NAF. The identified COI or CTI can be considered a constraint and, in turn, result in a CTP. For this purpose, the KPI formulation can be achieved using a dedicated table that includes all items from the structural and hierarchical proposal, as well as the KPI parameters described previously, at both strategic, operational, and tactical levels.

Hence, the NAF can be enhanced by integrating the KPI concept and utilising the structural and hierarchical model proposed in this research to accurately verify the EA status. Consequently, the expected results will be attainable.

Therefore, generic KPIs can be developed without needing to fill in all fields. The development of generic KPIs was tailored to an EA framework for security and defence, which aligns entirely with the NAF doctrine. As such, the generic KPIs can be incorporated into an updated version of NAF. The identified COI or CTI can be viewed as a constraint, which, in turn, may lead to a CTP. For this purpose, KPI formulation can be conducted using a dedicated table that includes all items from the structural and hierarchical proposal, along with the KPI parameters, at strategic, operational, and tactical levels.

It can be observed that the NAF can be enhanced by utilising KPIs through an implementation process that leverages a structural and hierarchical model proposed in this research, which aligns with and accounts for their essential dependencies. It is expected that failing to improve the NAF in this regard will prevent the proper verification of an EA's status; therefore, the expected results will either not be achieved or will be difficult to attain. Below is a proposal for representing the NAF gridlines that includes KPIs in its metamodel (Table 4).

Table 4 – Proposal for new NAF metamodel with KPIs

					Behaviour					
	Taxonomy	**Structure**		**Connectivity**	**Processes**	**States**	**Sequences**	**Information**	**Constrains**	**Roadmap**
Concepts	C1 Capability Taxonomy NAV-2, NCV-1 **(KPI model)**	C2 Enterprise Vision NCV-1 **(KPI model)**		C3 Capability Dependencies NCV-4	C4 Standard Processes NCV-6	C5 Effects **KPI model**		C7 Performance Parameters NCV-1 **(KPI model)**	C8 Planning Assumptions	Cr Capability Roadmap NCV-3
	C1-S1 (NSOV-3)									
Service Specifications	S1 Service Taxonomy NAV-2, NSOV-1 **(KPI model)**	S2 Service Structure NSOV-2, 6, NSV-12		S3 Service Interferences NSOV-2	S4 Service Functions NSOV-3	S5 Service States NSOV-4b	S6 Service Interactions NSOV-4c	S7 Service I/F Parameters NSOV-2	S8 Service Policy NSOV-4d **(KPI model)**	Sr Service Roadmap **(KPI model)**
Logical Specifications	L1 Node Types NOV-2 **(KPI model)**	L2 Logical Scenario NOV-2 **(KPI model)**	L2-L3 (NOV-1)	L3 Node Interactions NOV-2, NOV-3 **(KPI model)**	L4 Logical Activities NOV-5 **(KPI model)**	L5 Logical States NOV-6b	L6 Logical Sequence NOV-6c	L7 Information Model NOV-7	L8 Logical Constrains NOV-6a	Lr Lines of Development NVP-2 **(KPI model)**
					L4-P4 (NSV-5)					
Physical Resource Specifications	P1 Resource Types NAV-2, NCV-3, NSV-2a, 7,9,12 **(KPI model)**	P2 Resource Structure NOV-4, NSV-1		P3 Resource Connectivity NSV-2. NSV-6 **(KPI model)**	P4 Resource Functions NSV-4	P5 Resource States NSV-10b	P6 Resource Sequence NSV-10c	P7 Data Model NSV-11a, b	P8 Resource Constrains NSV-10d **(KPI model)**	Pr Configuration Management NSV-8 **(KPI model)**
Architecture Foundation	A1 Meta-Data Definitions NAV-2	A2 Architecture Products Nav-1		A3 Architecture Correspondence ISO 42010	A4 Methodology Used NAF CH-2	A5 Methodology Status Nav-1 **(KPI model)**	A6 Architecture Versions NAV-1	A7 Architecture Compliance NAV-3a	A8 Standards NTV-1/2 **(KPI model)**	Ar Architecture Roadmap

Source: adapted from (NATO, 2026, p. 79)

It is anticipated that, through the proposed structural and hierarchical model, KPIs will be inherent, as they are necessary in conjunction with CI, COI/CTI, MoE/MoS, and MoP, thereby leading to a significant increase in the evaluation of an EA using the NAF. Four central gaps in the NAF urgently require attention, namely: (i) Absence of dedicated viewpoint: no single viewpoint for high-level KPI definition and visualisation (C7 is for capability parameters, but there is no formal Architecture Performance Dashboard) (Müller, Segor, Mühlenberg, Driessen, & Geus, 2023); (ii) Required metamodel: the lack of “Indicator” and “Measurement” classes in MODEM/UAF prevents the representation of KPI entities as primary elements (Halvorson & Thomas, 2022); (iii) Incomplete assessment process: NAFv4 references ISO 42030 for assessment but does not specify which metrics to use or how to incorporate them into the architecture lifecycle (ISO, 2019b); and (iv) Limited integration with tools: there is no guidance for automating data extraction (via SMM) or for creating dashboards connected to the model (Zabala-López, Linares-Vásquez, Haiduc, & Donoso, 2024).

3.6. Formulation of Key Performance Indicators for Enterprise Architecture about Maritime Security

Thus, a set of generic KPIs can be formulated using the structural and hierarchical model proposed in the research, without the obligation to fill in all structural parts; instead, follow the chosen structure. The formulation of generic KPIs was adapted to an EA structure for the security and defence domain, with a predominance of maritime security entirely associated with the NAF doctrine. An analogy between the following table and military operational planning, typically used in COPD, is shown below. The objectives relate to the Military Strategic Objectives (MSO), and the CI relates to the Military Strategic Effects (MSE). The COI or CTI is related to the

Military Strategic Actions (MSA), demonstrating that the proposed hierarchical structure for building KPIs aligns with the doctrine currently used at the military level.

The KPIs identified for the EA regarding maritime security, focusing on increasing cooperation and articulation of interested stakeholders in the information domain, were as follows:

- Annual EA cost decrease percentage.
- Annual optimisation rate of material and personnel resources.
- Annual success rate of initiatives to increase information flow and sharing.
- Annual success rate of initiatives conducted to increase information flow and sharing.
- Annual percentage of interoperability between systems.
- Annual rate of joint and combined shares between stakeholders.
- Annual percentage of Command and Control (C2) established and implemented.
- Percentage of organisational goals supported by EA.
- Average time needed to implement EA changes.
- Percentage of users satisfied with EA.
- Annual percentage of the number of security breaches or incidents.
- New partner identification rate.
- Share rate between stakeholders.
- Percentage of cooperation between stakeholders.

Thus, filling an entire table with the KPIs defined for EA regarding maritime security requires extensive table development, which is incompatible with the proper document dimensions. Hence, the following table shows just one example using KPIs associated with the table proposed in the investigation: the KPI-share rate between stakeholders (Figure 8).

Vision	Mission	Values and Policies	Directives and Rules	Processes and Methods	Category BSC	Strategic Intent	Goals	KPI	CI	COI	CTI	MoE	MoS	MoP	TPM
Stakeholder satisfaction	*Increased overall stakeholder satisfaction.*	Increased stakeholder satisfaction without jeopardising the organisation's proficient EA	Increased bilateral and multilateral activities among stakeholders	Develop procedures for personnel exchange	Stakeholders (customers)	Increased staff interaction at EA	Increase functional exchange	Annual percentage increase in stakeholder coordination	Architecture for maritime safety enhances stakeholder engagement in environmental education	Increase personnel exchange between stakeholders		Increase staff exchange as a percentage		Increase staff exchange by 15%	
										Establishing relationships between stakeholders		Increase consistency in the functional relationship between stakeholders to twice the current level		Increase consistency in the functional relationship between stakeholders by 50%	
												Establish points of contact between all stakeholders		Establishing points of contact between stakeholders at 100%	Establish an annual Standard Technical Procedures (STP)
									Architecture for maritime security increases the degree of informational automation in the EA		Increase the level of information automation		Increase the level of automation in processing percentage information	Increase the level of automation in information processing by 25%	Establish an annual Standard Technical Procedures (STP)
													Increase the percentage of stakeholders using the services	Increase the number of users by 50%	
									The architecture for maritime security aims to enhance the Memoranda of Understanding (MoU) and agreements in the EA	Increase in bilateral and multilateral MoU and agreements		Increase the production of MoU at the bilateral and multilateral levels as a percentage		Increase the production of MoU at the bilateral and multilateral levels by 50%	
												Increase bilateral and multilateral agreements as a percentage		Increasing bilateral and multilateral agreements by 50%	

Figure 8 – Proposal of a set of KPI using the structural and hierarchical model proposed in the research, for the construction of an EA for security and defence (maritime security)

In addition, the implementation of an EA with the objective of coordinating and articulating all Operations Centres, under the leadership of a single entity, would allow faster and more substantial access to information, thus providing information superiority and early warning, and consequently greater speed in combating all types of threats and risks in the maritime domain.

4. Enterprise Architecture for maritime security

To implement the EA model for maritime security in an information architecture type and a coordinative style (NATO, 2026, p. 28) in various contexts and ensure flexibility according to requirements, the NAF provides a standard guide during the architecture-building process, providing eight steps, each with a defined purpose (Table 5).

Table 5 – Description of architecture stages for maritime security in eight steps

	STAGES	DESCRIPTION
1	Establish Architecture Landscape (AL)	Develop an informational EA at a coordinating level for global maritime security, encompassing all stakeholders. EA aims to ensure maritime security by mitigating vulnerabilities and enhancing opportunities, thereby enabling information exchange and achieving information superiority. To achieve this, all stakeholders must use all available systems, forces, means and capabilities.
2	Establish Architecture Vision (AV)	Effective information sharing and coordination among all stakeholders are crucial to maritime security, particularly given the threats and risks posed by the maritime domain.
3	Describe Alternatives of Architecture (AD)	Quickly exchange information about threats and risks in the maritime domain, using structures already implemented at local and regional levels.
4	Evaluation Alternatives of Architectures and Propose Trade-Off (AE)	At global level intends to: (i) guarantee cooperation and information exchange procedures; (ii) ensure the connection, interoperability and systems integration; (iii) increase top-down and bottom-up information; (iv) conduct joint and combined activities; (v) reduce EA complexity; (vi) share naval forces; (vii) prepare joint and combined plans; and (viii) encourage joint participation.
5	Develop and Maintain a Migration Plan (MP)	Connection between all organisations, entities, and agencies to implement EA.
6	Govern Application of Architectures (AG)	A connection between all stakeholders in a network to quickly share and exchange information, enabling early warning.
7	Decide on Architecture Changes (AC)	Implement EA changes in response to stakeholder requests after conducting a technical feasibility analysis.
8	Manage Architecture Motivation Data and Dashboard (MD)	Implement a C2 system [i.e., establish an Operational Headquarters (OHQ) in Allied Maritime Command (MARCOM)] to ensure EA management and provide pertinent information on the status of the architecture's progress and its dependencies with other architectures through a dashboard that aligns the products with the operational environment (libraries and reference repositories) [The MARCOM is the best organisation for this purpose, through coordination between its Member States and partners. If the EU also intends to implement a similar organisation, the Military Planning and Conduct Capability (MPCC) plays the same role as MARCOM].

Source: (NATO, 2026, p. 43)

Henceforth, the Sparx Systems 16.1 program, designed for building an EA, was used by the NAF to develop the EA viewpoints on maritime security. Therefore, using the two-dimensional NAF network representation for viewpoints, the first line refers to the NAF grid's concepts, which support the analysis and optimisation of resource delivery aligned with the organisation's strategic intent, aiming to capture the vision, strategic organisation, concepts, and capabilities.

The following figures illustrate how the maritime security architecture can be developed. However, the appropriate document dimensions prevent the display of all viewpoints, demonstrating the effectiveness of the EA for maritime security. Nonetheless, Figure 9 presents the C1 viewpoint on EA for maritime security.

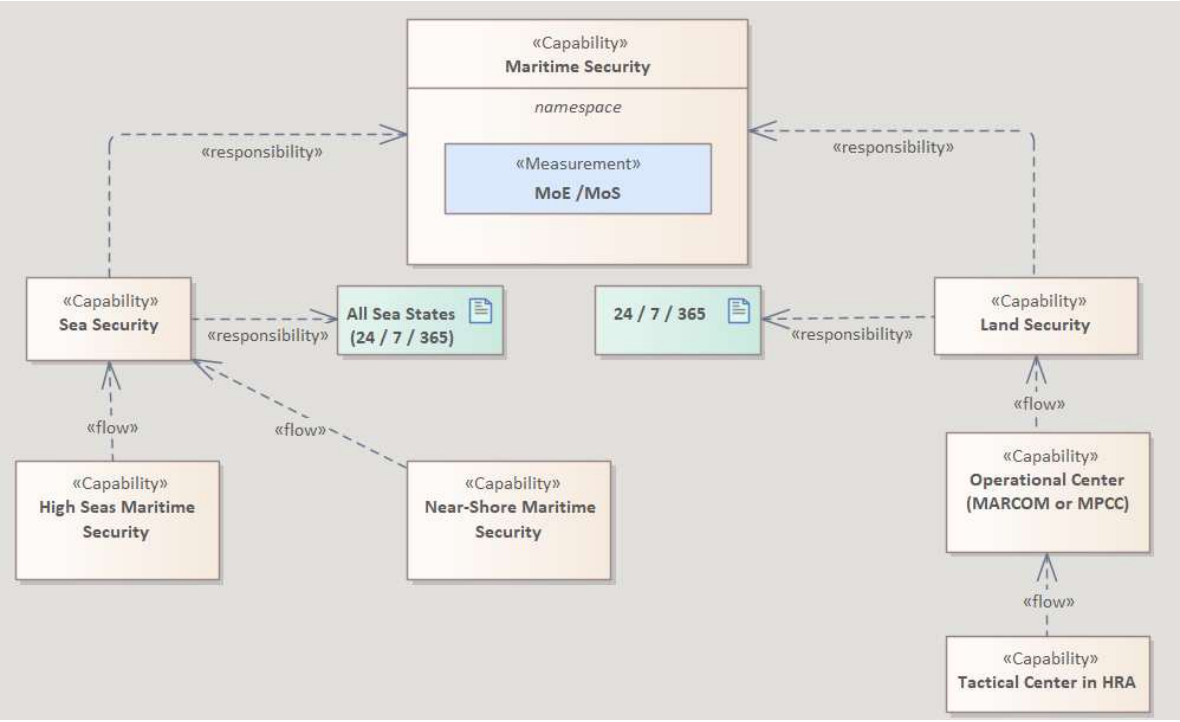


Figure 9 – Viewpoint C1 on EA for maritime security

Regarding the Service Specifications line of the NAF grid, which aims to support the description of services regardless of their implementation or use, Figure 10 highlights viewpoint S1 on EA for maritime security.

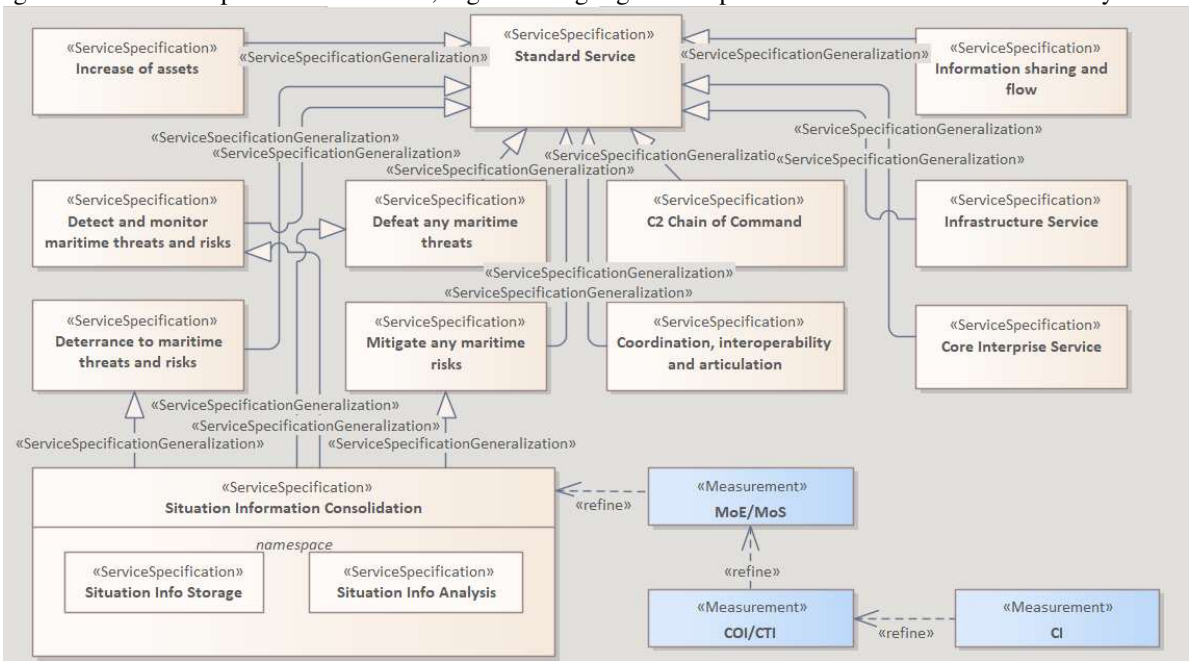


Figure 10 – Viewpoint S1 on EA for maritime security

The third line refers to the Logical Specifications viewpoints of the NAF grid, which support independent solutions by describing logical nodes (capability elements), activities, and exchanges of resources and information necessary to conduct missions. These missions include both combat operations and business processes. Therefore, Figure 11 highlights viewpoint L1 on EA for maritime security.

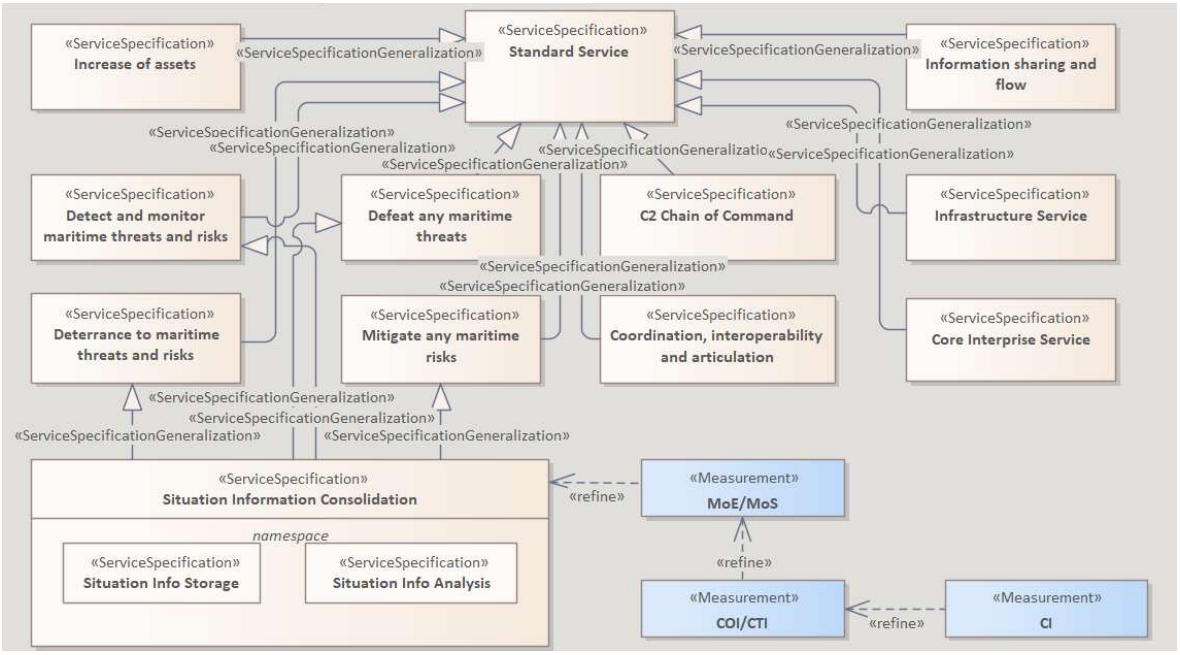


Figure 11 – Viewpoint L1 on EA for maritime security

The fourth line refers to the viewpoints of the Physical Resource Specifications of the NAF grid, which support the description of the structure, connectivity, and behaviour of various resource types. These include people, organisations, artefacts, software, and any combination of these. Therefore, Figure 12 highlights viewpoint P1 on EA for maritime security.

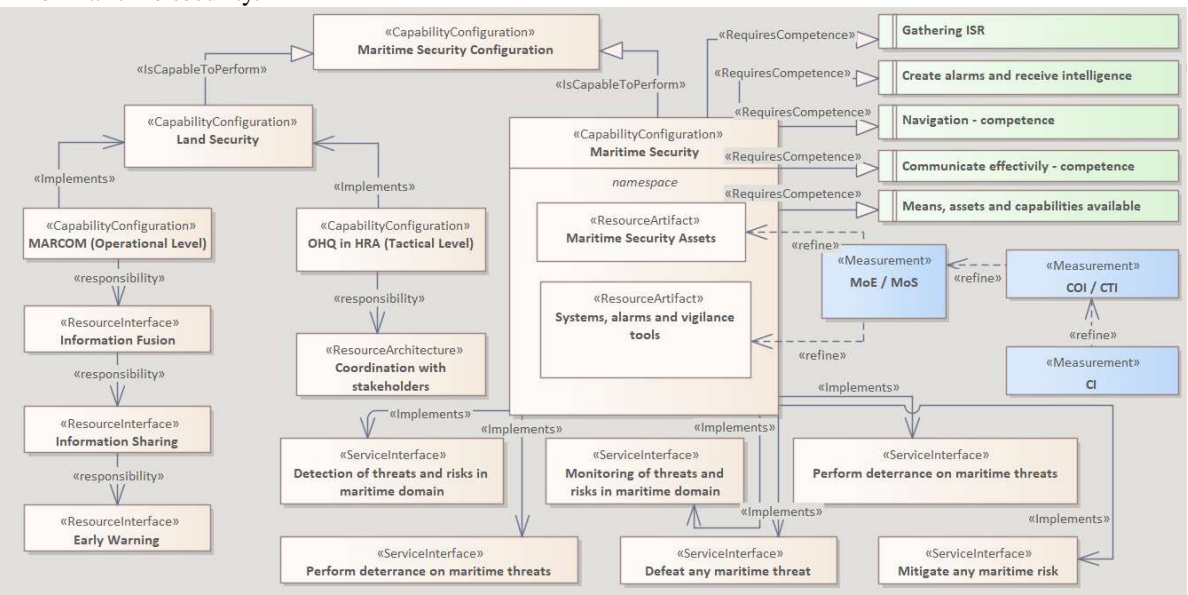


Figure 12 – Viewpoint P1 on EA for maritime security

The last line refers to the Architecture Foundation's perspectives on the NAF grid, which supports the administrative aspects of the architecture, such as who created it, for whom it was created, and when it was created. Each perspective is detailed and can be traced back to the individual concerns of specific stakeholders. Therefore, Figure 13 highlights perspective A1 on EA for maritime security.

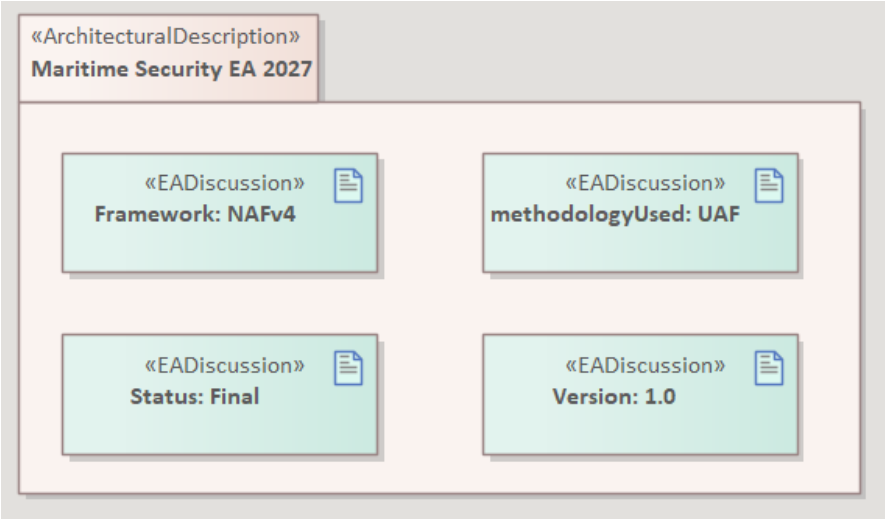


Figure 13 – Viewpoint A1 on EA for maritime security

All other viewpoints of the NAF metamodel could be presented, but by highlighting only the first viewpoints of each line, the goal of proving an EA for maritime security is assured. Therefore, the EA for maritime security is based on the combination of viewpoints from the Concept, Service Specification, Logical Specification, Physical Resource Specification, and Architecture Meta-Data lines, as outlined in the NAF. The EA dedicated to maritime security is an excellent tool, making it easier to implement, test, train, and integrate the EA into normal operations at both operational and tactical levels quickly and professionally.

5. Methods

Next, it will present generic terms for the methods used, data sources, and techniques, and identify gaps and limitations in past studies, concluding with an assessment of the risk-of-bias analysis for the SLR, performed using the ROBIS tool and the GRADE system.

5.1. Approach

From an epistemological perspective, and to achieve the objectives of this paper and to develop this process and methodology, the case study method was employed (Bryman, Clark, Foster, & Sloan, 2021). This focused on the NAF, the NATO EAF, the integration of KPIs into the NAF metamodel, and the development of an EA for maritime security within a qualitative analysis. Furthermore, this process must address two main RQ, which aim to develop two hypotheses. The data for the case study were collected, analysed, or validated from NAF doctrine (NATO, 2026); (NATO, 2019) to support conclusions about NAF and the feasibility of integrating KPIs, while other data were gathered from various publications.

5.2. Data Sources

The sources used were NATO publications on the NAF and various papers on the KPIs. Furthermore, the NAF assessment and the KPIs concept were based on several papers and books published, with a focus on NATO publications, using the DSR method, that is, to understand the problem, present solutions, develop a new concept, more specifically about the KPIs integration into NAF metamodel and the EA for maritime security and subsequent evaluation, presenting conclusions, all based on a transversal way of viewing the problem, between the current and the proposed structure, based on a qualitative approach to the information collection, using hypothetico-deductive reasoning, which preliminary data are presented in this paper.

5.3. Techniques

The bibliographic review aimed to gather information on analytical elements and document the SLR review process. In addition to this tool, the implementation of the research strategy is based on three main techniques: (i) data collection methods, which include a combination of techniques such as EA artefacts, security policies, and reports, to understand the NAF organisations and their impact on the security and defence domain, as well as the KPIs model; (ii) data analysis techniques: qualitative and quantitative data analysis methods were employed; (iii) assessment framework: drawing on established literature on maritime security, an EA assessment framework was created. No issues were recorded during the research, allowing the methodological approach to be completed.

5.4. Research limitations

The NAF metamodel has not incorporated the KPI concept in a structured, hierarchical manner. Consequently, it cannot accurately measure goal performance, nor can it serve as a basis for benchmarking, litigation, decision-making, and resource optimisation at the strategic level. Therefore, it does not provide a convenient, efficient means to verify the EA status, so the expected results will be neither achievable nor practical. Nonetheless, the limitations identified during the investigation include the lack of KPI formulation, the possible KPI structure, and the integration of KPIs into the EAF metamodel and the NAF.

5.5. Risk of bias analysis on SLR performed using the ROBIS tool and the GRADE system

Based on the verified analysis of the SLR, for the RQ1 and RQ2, it was possible to confirm that there is already a wide variety of articles and studies published, regarding its two subjects, however, a solution to formulate KPI based on hierarchical structure, extension of the NAF metamodel to include KPI and the construction of an EA for maritime security using the NAF still needs to be presented.

Thus, the comprehensive assessment using the Risk of Bias in Systematic Reviews (ROBIS) tool (Gómez-García, et al., 2017), which addressed all guiding questions across all domains, found the review results to be dependable. A low potential risk of bias was identified during the review process, and any biases found were mitigated. Similarly, the possible limitations of the included studies were thoroughly discussed. The conclusions were evidence-based, drawing on a diverse database and considering the relevance of the included studies. Furthermore, additional search methods were reported, and the search restrictions were justified.

Similarly, it assumes that there are no constraints on the methods used for data collection and study evaluation, as the quality, quantity, and detail of the articles were assessed, thereby enabling interpretation of the results. Finally, it assumes there were no limitations regarding the synthesis of results, as the analysis methods employed in this review were the most robust, dependable, and diverse. Likewise, details of the studies were provided, and a formal risk-of-bias assessment was conducted to determine whether the studies differed from one another.

The analysis of bias risk using the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) system indicates that, although the initial confidence level was low due to the observational nature of the studies, it can be improved. This was achieved because a large effect size was observed, a dose-response gradient was present, and no bias was detected (Prasad, 2024).

The risk analysis process using the GRADE system was developed based on articles from online sources that addressed the two RQ topics, either comprehensively or partially, along with their respective hypotheses. Thus, two tables were constructed: one with 126 articles for RQ1 and another with 82 for RQ2. These articles were quantitatively marked as one or zero for each RQ or hypotheses raised, indicating whether or not they addressed the RQ or hypotheses in a column marked 'present' or 'absent'. As a result, the research significantly increased confidence in the effect estimate, leading to a potentially low risk of bias (Mendoza, et al., 2017).

Similarly, for RQ1, the inconsistency analysis showed low variation in the results, with an RR of 1.54. This means that the RR of an association between the formulation of KPIs for monitoring and evaluating EA in the security and defence domain is 1.54 times greater than the likelihood of incorporating KPIs into the NAF metamodel. In this case, there is a risk factor regarding RQ1, as evidenced by the extensive literature on KPIs, including some focused on security and defence; however, a notable gap remains in the literature on incorporating KPIs into the NAF metamodel.

Instead, the 95% Confidence Interval (CI) ranged from 1.03 to 3.03, with the Lower Limit (LI) and Upper Limit (UL) at 1.03 and 3.03, respectively. The results also demonstrated low imprecision (Table 6). They provided direct evidence that the available data address RQ, as shown by the application of the PICO methodology. Finally, there was no publication bias, as indicated by the positive results and the broad scope and inclusion criteria. The following Table summarises the RR and CI calculations for RQ1.

Table 6 – Final representation of the 95% CI in relation to RQ1

Exposure factor	Present	Absent	Total	RR (CI 95%)
RQ1	43	37	80	1.54 (1.03 – 3.03)
Hypothesis	16	30	46	
Total	59	67	126	

Likewise, for RQ2, the inconsistency analysis showed low variation in the results, with an RR of 1.8. This means that the RR of an association between the possibility of introducing KPIs into the NAF metamodel and the

possibility of validating a NAF proposal applied to the EA and maritime security domains is 1,8 times greater than the possibility of validating a NAF proposal applied to the EA and maritime security domains. In this case, there is also a risk factor related to RQ2: although some literature exists on introducing KPIs into the NAF metamodel, there is a lack of literature on validating the NAF in the EA and maritime security domains.

Instead, the 95% CI ranged from 0.41 to 2.41, representing the LI and the UL. The results also demonstrated low imprecision and provided direct evidence that the available data address RQ2 when the PICO methodology is applied (Table 7). Finally, it was also clear that there was no publication bias, as shown by the positive results and the broad scope and inclusion criteria. The following Table summarises the RR and CI calculations.

Table 7 – Final representation of the 95% CI in relation to RQ2

Exposure factor	Present	Absent	Total	RR (CI 95%)
RQ2	19	23	42	1.8 (0.41 – 2.41)
Hypothesis	10	30	40	
Total	29	53	82	

From the analysis of the risk of bias using the GRADE system, it can be seen that, although the initial level of confidence was low because they were observational studies, it was possible to increase this same confidence, as it was possible to obtain a large magnitude of effect, a dose-response gradient and no bias, therefore, the research had a significant impact on the confidence in the estimate of the effect, thus obtaining a potentially low risk of bias.

6. Results

In this investigation, an SRL was conducted to incorporate KPIs into the NAF metamodel, which includes a structure for KPI conception, thereby enabling it to address the two RQs established for this investigation, which empirically support the proposed model or method, elevating writing quality and structural organisation, expanding the literature review, and aligning with current academic standards. At SRL, the PICO model was utilised to establish the conditions for developing a military EA under the auspices of the NAF (population). This process incorporated metrics and KPIs into the NAF metamodel (intervention) and compared them with EA based on the UAF and related standards, such as ISO (comparison). This ultimately enabled the integration of KPIs into the NAF metamodel, with an EA focused on maritime security.

NAF enables the creation of collaborative EAs using its metamodel in security and defence, supporting good governance and management within any organisation. However, it does not incorporate KPIs into its metamodel. This EA for maritime security, including the KPIs, must be suitable for management to identify and mitigate vulnerabilities and capitalise on favourable opportunities throughout its lifecycle. Considering the external and internal environment at a global level, the EA structure must be resilient and accommodate all stakeholders, processes, stages, and the necessary artefacts.

The investigation addressed the NAF methodology, viewpoints, KPI principles, the integration of KPIs into the NAF metamodel, and the development of an EA for maritime security. It also involved creating KPIs for EA in the security and defence domain and validating them by applying NAF to EA for maritime security. Additionally, introducing KPIs in NAF improves EA governance and maritime security management. For this research, the case study method was used (Bryman, Clark, Foster, & Sloan, 2021).

In this sense, the NAF potential was validated when KPIs were integrated into the structural and hierarchical model, enabling the development of collaborative EA, primarily in the security and defence sector. This facilitates effective governance and organisational management, enables proper oversight of all stakeholders, mitigates vulnerabilities, and capitalises on opportunities for the existing EA. It supports continuous management throughout its lifecycle, enhances information exchange among stakeholders, and ensures information superiority. Consequently, it provides decision-makers with the tools to make informed decisions, leading to improved operational outcomes.

6.1. Findings

Two key points were analysed and developed: the integration of KPIs and the use of a hierarchical structure within the NAF metamodel, as well as the development of EA for maritime security. These are two specific aspects of how the NAF can be improved and how it can support security and defence operations within the framework of the Atlantic Alliance and its Member States, as well as beyond, which could pose a challenging factor in justifying the need to update the Atlantic Alliance publication itself.

6.2. Practical implications

The EA for maritime security was developed based on the NAF methodology and followed the doctrinal steps of the NATO publication as an innovative point about the KPIs incorporation, a pressing issue in the research, which served to verify the importance of its incorporation into the NAF metamodel, which could be a demanding factor for it to be considered necessary to update the Atlantic Alliance publication itself.

7. Discussion

The NAF methodology is analogous to the other EAF methods. NAF enables the creation of collaborative EA using its metamodel in security and defence, facilitating good governance and management within any organisation; however, it does not integrate KPIs into its metamodel. This EA for maritime security, which includes the KPIs, must be adequate for management to present to all stakeholders, thereby mitigating vulnerabilities and enhancing favourable opportunities for the EA throughout its lifecycle. Given the global external and internal environments, the EA structure must be robust and account for all stakeholders, processes, stages, and necessary artefacts.

7.1. Implications

Hence, this paper employed the case study method to investigate NAF, the incorporation of KPIs into the NAF metamodel, and the development of EA for maritime security, addressing two central questions and their respective hypotheses. Likewise, regarding EA for maritime security, the OHQ in Northwood, United Kingdom (UK), specifically at MARCOM, NATO's operations centre of excellence, was an obvious choice, given the organisation's experience, results, and status, and serves as the EA's coordinating centre for maritime security.

The alternative would be the EU MPCC, which could also undertake this role. However, this presents an operational issue regarding information exchange, as there may be classified data that cannot be shared with all stakeholders, particularly non-NATO partners, and can be disclosed only by Member States. In this case, there was a need to establish a specialised information-sharing process between Member States and non-NATO partners, involving the implementation and use of separate communication systems for classified and unclassified information.

7.2. Original Value

This process involves constructing the EA based on the NAF metamodel, with an emphasis on viewpoints and views. However, there is a noticeable gap in the NATO document, particularly in its strategic-level KPIs for the metamodel, which may affect other processes that depend on the operational and tactical levels. When defined, KPIs possess a series of characteristics and criteria that must be anticipated and adhered to. They are directly influenced by the mission and vision, which are political or strategic in nature, and these will affect the metrics measured at the operational, tactical, and even technical levels.

7.2.1. Broader Impact

The proposed structural and hierarchical model is fully adaptable to both the NAF metamodel and the UAF DMM. Specifically, it was found that extrapolating the structural and hierarchical model to the NAF metamodel is feasible and understandable, as it correlates with the concepts presented and the UAF DMM methodology.

7.2.2. Recommendations for improving the NAF

Given the data collected, in addition to incorporating the structural and hierarchical model for granting KPIs into its metamodel, it is essential to offer other concrete recommendations for NAFv4, focusing on which extensions to the MODEM/UAF metamodel are consensus-based, namely:

- Add the "Indicator" class and associations, aligning with the OMG SMM specification to ensure interoperability between Model-Based Systems Engineering (MBSE) tools. This will create the "KPI", "MeasurementSet", and "Measurement" entities in the NAF metamodel (OMG, 2018); (Kroculick, 2022); (Santos, Martins, & Molléri, 2025); (Grechi, Oliveira, & Braga, 2025).
- Create an "Architecture Performance Dashboard" viewpoint: within the Architecture layer (A), develop an A9 viewpoint that presents KPI synthesis in a tabular or graphical format, fed by data extracted from the model's "ActualMeasurement" (OMG, 2018); (Rosa, Mansfield, Jousselme, & Tremori, 2021).

- Standardise quality attributes: extend the L7 Logical Data Model and P7 Physical Data Model to include ISO 25010-based attributes (e.g., accuracy and precision, response time, availability), linking them to strategic KPIs (ISO, 2011).

Following the recommendations provided, a simple fictitious example of how to model, in NAFv4, a KPI of "mean incident response time" using viewpoint C7 (Performance Parameters) and integrating with viewpoint A9 (Architecture Performance Dashboard), could be the following: (i) Capability: response to maritime incidents; (ii) KPI: average response time; (iii) Description: time between detection and the unit's arrival at the site; (iv) Goal: less than 30 minutes; (v) Measurement: frequency of semi-annual data collection for the C2 system; (vi) Source: operational report; (vii) MOE: percentage of incidents responded to within 30 minutes; and (viii) MOP: alert latency under 2 minutes or average ship speed below 25 knots.

7.3. Theory and calculation

Overall, the NAF is an essential player, but it can be significantly improved by incorporating KPIs into its metamodel. This would enable verification of whether strategic objectives are achieved and the identification of gaps in an EA, ensuring it is a capable tool for addressing complex, evolving challenges in the security and defence domain today.

Currently, the NAF needs to develop four areas: (i) developing a formal KPI metamodel for NAF; (ii) creating dashboard tools for automated NAF; (iii) proposing an assessment process aligned with ISO 42030 and ISO 25010, thereby addressing the gaps previously identified in the NAF; (iv) integrating with tools for automating data extraction (via SMM), as well as creating dashboards connected to the model. Therefore, the following are three recommendations to improve the NAF, as mentioned earlier.

7.4. Key Takeaways

The main findings of the investigation are based on three points: (i) NAF is an excellent EAF for the security and defence domain. However, it needs to incorporate the KPIs concept into its metamodel to improve goal performance measurement and reduce risk at the strategic level; (ii) the development of an EA for maritime security, using the KPIs concept, facilitates a more structured organization and demonstrates that it is possible to create an EA for maritime security despite the numerous organizations, entities, and agencies, local and regional, that currently exist for this purpose; and (iii) it is necessary to establish a coordinating agency for the maritime security EA, which could be MARCOM or the MPCC.

Therefore, by building an EA for maritime security, using NAF with KPIs in its metamodel, it is possible to verify more accurately whether an organization's strategic objectives have been met, reducing costs and optimizing resources, that is, eliminating unnecessary expenses, minimise the impacts of maritime insecurity, making any organization related with maritime domain more manageable and even enabling better long-term planning, as well as maintain an acceptable quality of the maritime environment, and sustain the quality of life and resource supplies for future generations. On the other hand, an EA for maritime safety serves as a tool to enhance early warning, thereby providing superior information on threats in the maritime domain, since all stakeholders are interconnected and the flow of information is more intense and rapid.

It was also likely to confirm that, in terms of resource implications, the recommended intervention is not cost-effective enough to justify its implementation. As estimated, a financial reduction can be achieved by implementing an EA for maritime security, enabling the much-needed sustainability of the actions.

7.5. Future Research

Indeed, future research should focus on developing scientific studies about integrating new information technologies into an EA for maritime security, such as: (i) artificial intelligence; (ii) machine learning; (iii) metaverse; (iv) blockchain; (v) quantum computing; (vi) robotics; (vii) augmented reality; and (viii) cloud computing. These tools could become particularly significant for maritime security, including maritime safety and security.

8. Glossary

The main terms used in the paper are described below:

- Vision Statement: a formulation that provides a definitive description of a vision (NATO, 2019).

- Statement of Goal: a formulation that clearly describes goals and aims (NATO, 2019).
- Status Indicator Usage: shows an entity's state or level (NATO, 2019).
- Measure in Context: any measure considered in a particular context (NATO, 2019).
- Critical Issues: CI is categorised as a Critical Operational Issues (COI) or a constraint. Constraints can be political, cost-related, or specific technical problems, and are called Critical Technical Parameters (CTP). In defence projects, it is common to augment the Measures of Effectiveness (Measures of Suitability) - Measures of Performance - Technical Performance Measures [MoE (MoS)-MoP-TPM] framework with the definition of higher-level measures called COI, which are key to operational effectiveness and operational suitability issues that determine the system's ability to perform its mission(s). COI is critical to system effectiveness and suitability for examination and resolution during the Operational Test and Evaluation (OT&E). The COI is then supported by MoE or MoS, which MoP supports; each can be considered the aggregate measurement of the selected TPM. MoE, MoS, MoP, and TPM are defined in the MoE (MoS)-MoP-TPM taxonomy (Ryan, 2014).
- Use of Measures means expressing a quantity (NATO, 2019).
- Critical Technical Issues (CTI): Other entities or organisations also use CTI, a concept similar to COI, but focused on the technical aspects of evaluating specific engineering parameters and characteristics. Therefore, CTI is usually resolved based on the demonstration or evaluation of Key Performance Parameters (KPP), Key Systems Attributes (KSA) and CTP. The KPP, KSA, and CTP are a small number of TPMs that provide quantitative and qualitative information about a system. KPP and KSA reflect significant capabilities or characteristics when they fail to meet their limits, which may lead to the system selection or program being evaluated or terminated (Cortes, 2014). The term 'Constraints' can be applied to CTP (technical aspects that directly describe or quantify the system's performance or its interactions with other systems). CTP can impose limits in weight, length, area, volume, frequency, response, temperature, and electrical or magnetic limits (Ryan, 2014).
- Measure Category: a class or division of measures considered to have shared characteristics (NATO, 2019).
- MoE is used to assess the degree to which an entity meets intended goals or requirements, causing an intended effect (Ends). MoE focuses on the entity's outputs or results and can be used to measure effectiveness in achieving a specific goal or to evaluate changes in behaviour, capability, or operating environment. MoE is typically defined at a higher level and is operational. MoE can be validation measures related to suitability and purpose, generally resolved through OT&E (Ryan, 2014).
- MoS: used to assess the extent to which an entity or organisation is suitable for the intended use or purpose, also causing an intended effect (Ends). MoS describe the operational suitability of a system for its intended purpose in terms of technical, operational, and other relevant factors. MoS can help identify areas where operational improvements may be needed (Ryan, 2014).
- MoP: quantitative measures (interpretation) and a way of determining or evaluating a value by comparing it to a standard, to which a numerical value can be assigned, describing the physical or functional attributes of the system's performance (Ryan, 2014) (Blasch, Liu, Liu, & Zheng, 2018).
- TPM: They measure some system aspects to decide whether specified requirements are being met throughout the lifecycle and then apply them (Ryan, 2014).

The glossary presents only the main definitions of the structural and hierarchical model proposed for KPI design.

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