Modeling and Analyzing Enterprise Architectures to Examine the Feasibility of Network Centric Operations

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***Abstract*—Military forces of NATO states are often constrained to perform missions within the framework of Network Centric Operations (NCO) due to a joint and multinational environment requiring a high level of interoperability. The transformation and development of respective capabilities and systems are often tied to financial and time based expenditures. Thus, models of real NCOs are necessary to analyze risks, problems and development needs. Enterprise architecture models of a certain organization provide views from different perspectives to examine various aspects with the aim of supporting problem solutions. This work presents an approach to apply two different architecture frameworks for modeling NCOs examining various layers of a model for interoperability. Furthermore, analysis methods are introduced to assess the feasibility of NCOs.**

Keywords – Enterprise Architecture; Network Centric Operations; UML modeling; analyzing methods; TOGAF; NAF.

I. Introduction

The importance of acquisition and evaluation of information has become an essential component of military operations. Thus, military forces endeavor to optimize the information flow and to minimize technical and operational errors. Among the "classical" operational factors – forces, space and time – information is considered as the fourth decisive factor of successful warfare [1].

Coincidentally the introduction of new technological capabilities to gather, exchange and process information offers new opportunities of efficiency enhancement and optimization of resources.

In the late 1990s, the principle of NCOs (also called Network Centric Warfare) was developed to achieve information superiority, as well as firepower and command superiority involving an optimized mission execution [1][2]. The attainment of these benefits requires an essential transform in thinking and acting of respective military forces. Organizational, structural and technical changes are necessary as well. Furthermore, just like any other new development, there are risks and problems to face.

Since a couple of years the German Federal Armed Forces have used scientific approaches to analyze and document the forces' progression and transformation with the objective to realize NCOs. In this paper, the modeling and analysis of NCOs using the method of architecture are described. Thereby architecture supports interoperability, cost effectiveness and a common understanding of the concept of NCO.

The paper is structured as follows: Section II defines the term of NCO and discusses its advantages, risks and problems. Section III introduces the architectural approach and gives an overview of the architecture frameworks. Section IV describes the modeling of NCO and the usage of architecture tools applied to a model of interoperability. After that analysis methods of architecture products are presented followed by best practice hints and lessons learned in Section VI. Section VII contains the papers conclusion.

II. Network Centric Operations

NCO is a military warfare doctrine with the aim to optimally bring available forces and means into effect. The concept of the Federal Armed Forces [3] presets the theory of NCO as the groundwork for all missions of the German forces. Therefore, all missions are performed by reconnaissance, command, joint fires and support networks in all dimensions (land, air, navy, space, cyber).

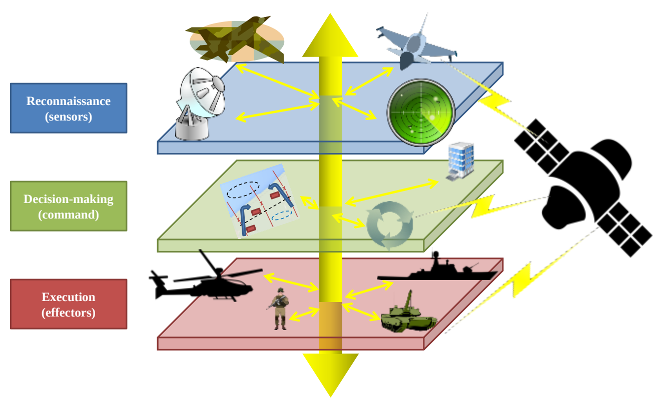

Figure 1. Scheme of Network Centric Warfare.

This requires a joint, cross-departmental, national, combined, interoperable and secure information and communication network embracing all levels of command. All units, duty stations and facilities together with sensors and effectors have to be connected using multinational and interoperable means to achieve a fast and efficient operation.

In contrast to a "Platform Centric Warfare" a network connecting multiple sensors, decision-makers and effectors as depicted in Figure 1 is able to create synergy by coupling system functionalities [4]. The information structure is based on a Common Operational Picture (COP) collecting and merging data from connected sensors. This improves the common situational awareness, informational superiority and command superiority in respective command facilities resulting in a fast, quick-response and effective use of effectors.

NCOs also contain some risks military forces have to avoid or reduce. The complexity of the COP could lead to an information overload especially on lower levels of command. However, a high level of detail could result in micromanagement on higher levels of command. Furthermore, the forces also have to provide a high quality of interoperability - operational and technical. Other risks might be the threat of cyber-attacks and vague responsibilities. Problems in the development of a NCO capability are the expensive costs of new technologies and a high financial and practical effort during the transformation.

III. Architectural Approach

A. *Enterprise Architecture*

An Enterprise Architecture is described as a well-defined practice for conducting enterprise analysis, design, planning, and implementation, using a holistic approach at all times, for the successful development and execution of strategy [5]. The basic idea of architecture is the systematic and structured description and analysis of a real and complex system by methodically disassemble the problem into smaller and simpler models of the reality without disregarding coherences and dependencies between these components. The definition of architecture terms and elements can be found in [6].

Architecture offers the opportunity to document complex sociotechnical systems. Thus, it is a reliable methodology to

- Verify operational deliberations and document an operational context,
- Deduce special user commands from the operational context,
- Design a technical solution to fulfil operational requirements,
- Abstract and document the internal structure of a technical solution as well as its inclusion in an overall system or network and
- Manage system and product dependencies.

Thus, enterprise architecture provides decision support of defining how resources will be used to support enterprise strategy and helps to achieve goals and objectives [7].

B. *Architecture Frameworks*

Due to the requirement of a structured and systematic development, architecture holds standardized patterns and process models for developing and using architecture products. Architecture frameworks contain valid conventions and guidelines for architecture preparation to ensure the models' and/or sub models' compatibility, integration, uniformity and reusability.

The variety of architecture frameworks is large and there are many different approaches. An overview of frameworks is given by Urbaczewski et al. [8]. Architecture frameworks used within military applications are compared by Jamjoom et al. [9].

The latter reference examines frameworks by focusing on their support of the Service Oriented Architecture (SOA) paradigm, which contains needs and capabilities and their distribution between stakeholders. With regard to Jamjoom et al. [9], the NATO Architecture Framework (NAF) strongly provides SOA features, such as interoperability and reusability, to implement NATO capabilities in complex operational environments.

Due to these benefits, the modeling of architecture products is based on rules and standards which are defined in the NAF Version 3.1 (NAFv3.1). Further on, an architecture development process is introduced in Section III.C by using The Open Group Architecture Framework (TOGAF).

C. *Architecture Development Method*

The development of enterprise architectures is guided by referenced process models to ensure a standardized, comprehensible and consistent way of projecting, implementing, analyzing and governing architectures. TOGAF characterizes a comprehensive approach to realize these requirements.

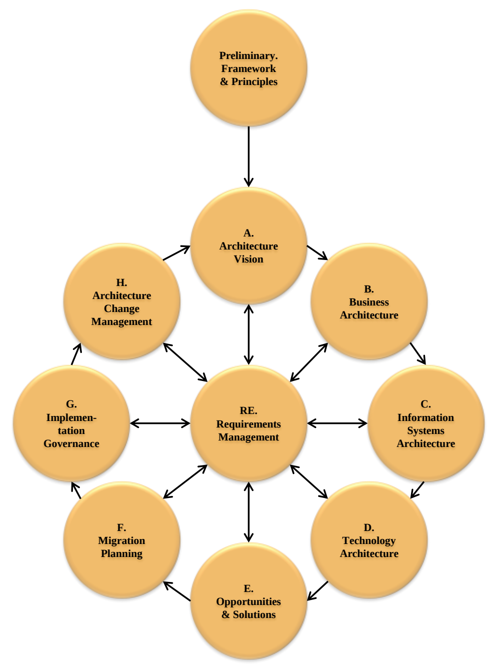

Figure 2. ADM correspondent to TOGAF [11].

Figure 2 shows the Architecture Development Method (ADM) designed in TOGAF to support the production, use and maintenance of enterprise architectures. This iterative cycle contains several activities and phases to realize an Enterprise Architecture in a controlled manner in response to business goals. Phases compliant with TOGAFs ADM are as follows [10]:

- Preliminary Phase: Initial phase to evaluate organizational frame for enterprise architecture, to analyze stakeholders and to identify affected organizational elements,

- Phase RE: Requirements engineering to survey, formulate, validate and manage requirements in every phase of the project.
- Phase A: The architecture vision validates capability requirements, organizational principles and business goals by developing an operational basic concept which defines the scope and relevant stakeholders of the architecture as well as key business requirements.
- Phase B: The business or operational architecture describes organizational, process and information aspects of the operational environment. This phase derives an operational and organizational structure by developing distributions of responsibilities and an information exchange process between authorities.
- Phase C: The development and implementation of data and application domains are part of the information systems architecture. The objective is to describe the support of business processes by information technology.
- Phase D: The technology architecture describes systems, system interfaces and dependencies for communication and interoperability aspects to support operational processes.
- Phase E: This phase evaluates and selects implementation options, identified in the development of the architectures developed in ADM before, by assessing dependencies, costs and benefits to generate a migration strategy and detailed implementation plans.
- Phase F: The objective of the migration planning is to prioritize projects to finalize a detailed implementation and migration plan.
- Phase G: The implementation governance formulates recommendations for realizing the implementation plan and manages the governance of the overall implementation and deployment process in the terms of capability improvement.
- Phase H: The phase of architecture change management establishes procedures for managing changes to initiate the development of a new architecture, thus a new iteration of the ADM

D. Views and subviews of the NAFv3.1

The NAF in Version 3.1 [7] proposes an elaborate content framework to model architecture products. It provides a range of convention and modeling rules on how to describe and document an architecture model. Therefore, the NAF defines “views” to consider an enterprise from an individual perspective. Dividing an individual view into a set of “subviews” supports the development of single architecture products, which can be analyzed easily by respective stakeholders. The views of the NAFv3.1 are:

- NATO All View (NAV): NAV describes overarching aspects and provides information, which are pertinent to the entire architecture including scope and context.
- NATO Capability View (NCV): The enterprises vision, goals and capabilities are modelled within the NCV by building e.g. taxonomies and dependency descriptions.
- NATO Operational View (NOV): The NOV conducts descriptions of derived tasks, activities, operational elements as well as information exchange processes that are necessary to fulfil missions.

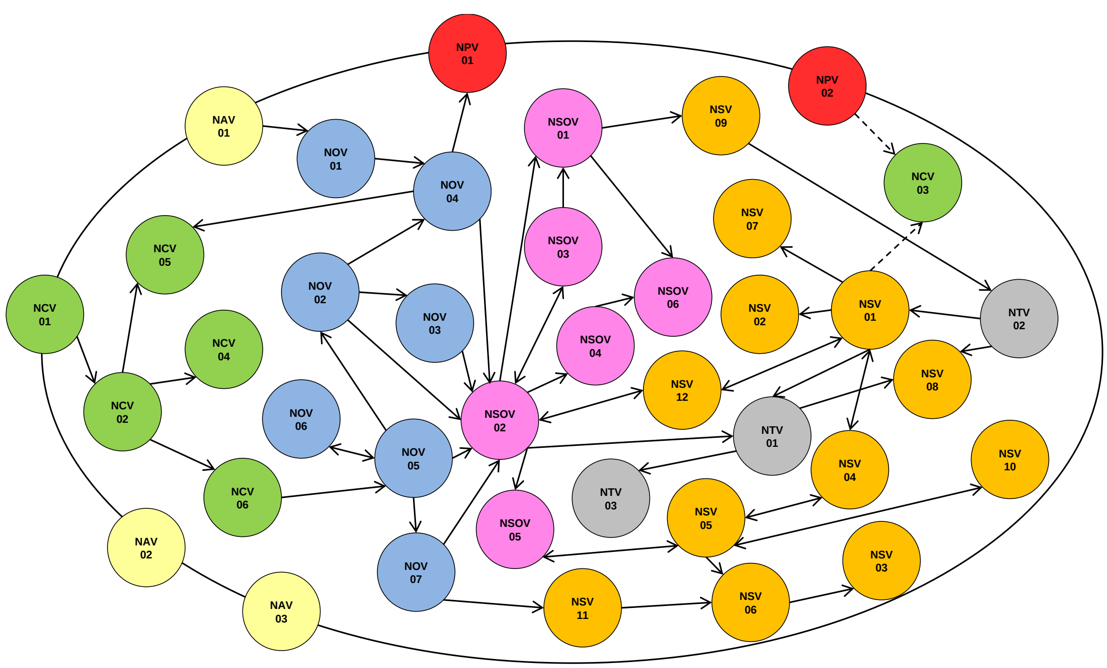

Figure 3. Arrangement of NAF subviews referring to [12].

- NATO Service-Oriented View (NSOV): The concept of SOA is fundamental to the NATO Network Enabled Capability (NNEC). The NSOV contains a description of services, which the provider provides as a useful result to a consumer to directly support the operational domain.
- NATO Systems View (NSV): The NSV contains subviews to describe the structure, interfaces and interconnections as well as functionalities of technical resources. Systems can provide services and support operational activities.
- NATO Technical View (NTV): Technical Standards, implementations and conventions are parts of the NTV.
- NATO Programme View (NPV): Products of NPV describe the relationships between capability requirements and implemented programs and projects.

The subviews are presented in a detailed manner in chapter 4 of the NAF [7]. In Figure 3, the subviews are arranged to show their dependencies within the structure of the NAF. On the left hand side (in green and blue), we have the perspective of the consumer, who performs operational activities and thereby consumes services to realize enterprise capabilities. On the right (yellow and grey), there are descriptions of technical systems providing functionalities to support operational processes. Both sides are connected by service-oriented views (purple) decoupling operational views from system views.

IV. MODELING NCOs

NCOs are, e.g., military evacuation operations. Therefore, forces of all military domains, especially Special Forces and navy supported by air force units deployed for this operation have to cooperate in a quick-response manner, which requires a high level of interoperability.

But, how can we define and examine interoperability to validate and develop respective capabilities and technology? In Tolk [16], Turnitsa [17] and Tolk et al. [18], a conceptual model abstracting and simplifying the terms of interoperability on various levels is presented, developed and applied. The Levels of Conceptual Interoperability Model (LCIM) introduces different layers of interoperation and describes their relation to the ideas of integratability, interoperability and composability [18]. The seven levels are defined as follows:

- Level 0: No interoperability, i.e., stand-alone systems.
- Level 1: Technical interoperability, i.e., established communication infrastructure allowing the systems to exchange data.
- Level 2: Syntactic interoperability, i.e., application and definition of a common data format to exchange information.
- Level 3: Semantic interoperability, i.e., unambiguous definition of the content of exchanged information.
- Level 4: Pragmatic interoperability, i.e., unambiguous definition of context, methods and procedures to use exchanged information.
- Level 5: Dynamic interoperability, i.e., changing system states and their effects – including the effects of information exchanges – on operation and data interchange are unambiguously defined.
- Level 6: Conceptual Interoperability, i.e., alignment of assumptions and constraints of the meaningful abstraction of reality [18].

NAFs SOA, as presented in Section III.D, has a high degree of support for interoperability, because of focusing on standardization and supporting the need for autonomy of systems [13]. Thus, the NNEC Feasibility Study pointed the SOA as a key to meet interoperability requirements, because

TABLE I. NAF SUBVIEWS ASSIGNED TO TOGAF PHASES (BASED ON [15]).

		A	B	C	D	E	F	G	H
NAV	1	■						□	
	2		■						
	3					■			
NCV	1	■	□					□	□
	2	■	□					□	
	3				■	□		□	
	4				■	□		□	
	5		■	□	□		□		
	6		■						
NOV	1	■	□					□	
	2		■						
	3		■						
	4		■						
	5		■						
	6		■						
	7		■	□					
NSOV	1		■	□					
	2		■	□	□			□	
	3		■						
	4		■						
	5		■	□					
	6		■	□		□	□	□	
NSV	1				■				
	2				■				
	3				■				
	4			■	□				
	5			■	□				
	6			■					
	7				■				
	8					■	□		
	9					■			□
	10			■	□				
	11			■	□				
	12		■	□	□				
NTV	1				■				
	2					■			□
	3					■			
NPV	1					■	□	□	
	2					■	□	□	

of its flexible, modular approach for implementing system functional requirements in the form of accessible and utilizable services [14].

To model capabilities, operations and/or missions for the purposes of examining their feasibility within the meaning of Network Centric Warfare on every single level of interoperability, we utilize the presented architectural methodology and content-related conventions from Section III. Referring to Jørgensen et al. [15] “TOGAF proposes an elaborate methodology and a simple content framework, while NAF contains a simple methodology and an elaborate content framework. The two approaches are thus complementary.” Combining advantages of both, NAF and TOGAF, we can connect the content-related guidelines of NAF subviews to the compelling development methodology of TOGAF phases. This mapping is visualized in Table I. By using this mapping, we can easily derive guidance for modeling enterprise architecture for NCO by focusing on services. In this table, the initial version of a subview is colored in dark blue. Further developments and/or changes of a subview are expressed in light blue.

We applied Unified Modeling Language (UML) [21] as an object oriented, graphical modelling language by using SPARX Enterprise Architect (SPARX EA) to model single NAF subviews in the prescribed order given by TOGAF. The intent is to examine and analyze every layer of interoperability by modeling processes, systems and services to make a point about the feasibility of respective NCOs. Therefore, existing technical, operational or capability gaps requiring further development have to be spotted and recommendations have to be made.

To express the relationship between architecture views according to NAFv3.1 at application level in SPARX EA Figure 4 depicts an UML class diagram showing single architectural elements and dependencies among themselves.

Starting with establishing a NAV-1 to present the actual problem area and the scope of the architecture, the capabilities, which have to be examined, are described in the form of taxonomies derived from the actual architecture vision in NCV-1 and NCV-2. Additionally, NOV-1 presents the operational concept on high-level. Thus, conceptual interoperability can be investigated.

In phase B, it is necessary to derive *OperationalActivities* from *Capabilities* (NCV-6) and model the placed order in the context of the operation and derived tasks thereof within the “Operational Activity Model” of NOV-05. Process models support the view on tasks and processes to describe real events and activities of the operation. To obtain clarity within the operational model at different levels of abstraction, it is recommended to build an activity hierarchy. Thus, the model can provide a better overview and activities can be structured easily. Operational constraints, states and timing descriptions are arranged in NOV-6 diagrams to support the modeling of dynamic interoperability.

Allocation of responsibilities can be modeled in an “Operational Node Relationship Description” (NOV-2) by mapping identified *OperationalActivities* to involved authorities, so called operational nodes. Furthermore, NOV-2

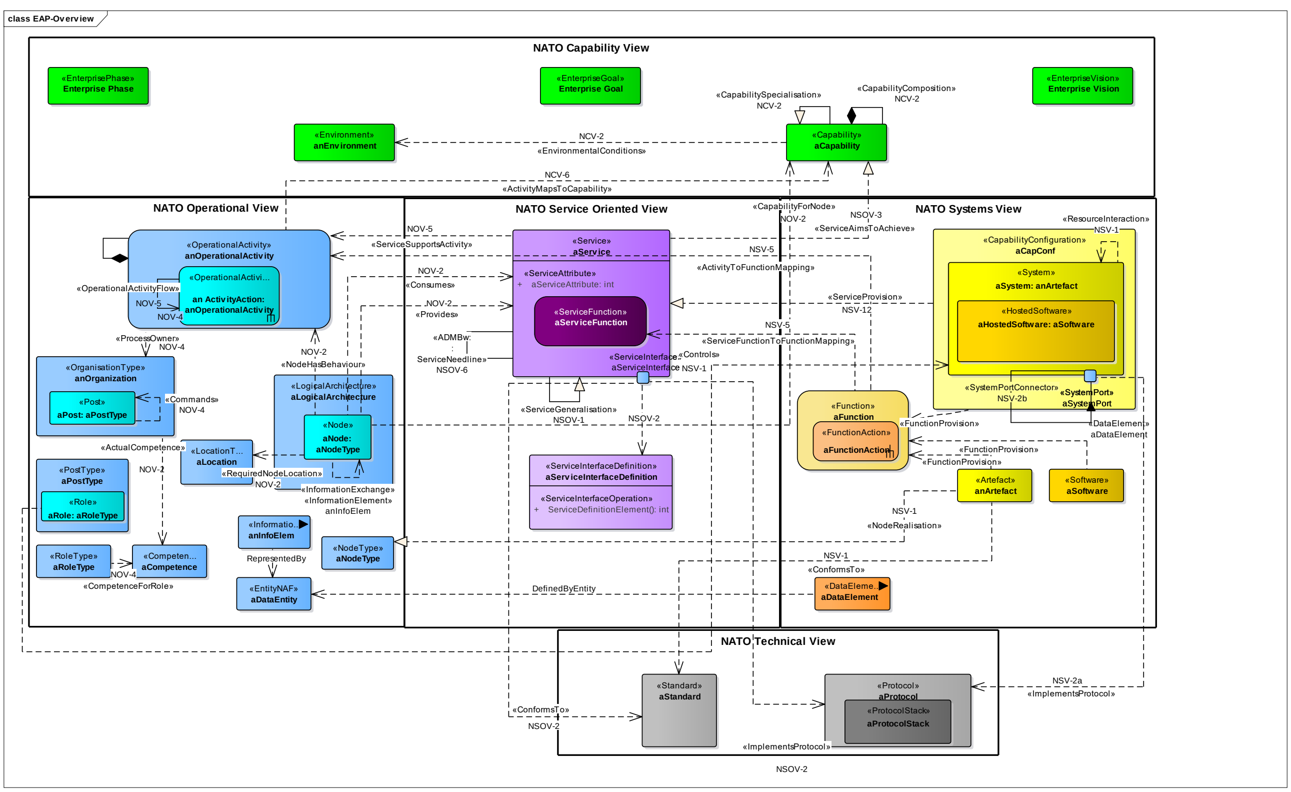

Figure 4. Selection of important NAFv3.1 elements and connections.

describes the information exchange between authorities to model their relationship, dependencies and the requirements according to operational and therefore, pragmatic interoperability. Using SPARX EA one can easily derive an "Operational Information Exchange Matrix" (NOV-3) from NOV-2 models resulting in an easy to read overview of information exchange elements, which can be analyzed significantly better. The actual or intended organizational structure among identified key players including command and control (C2), hierarchical and functional relationships, e.g., required competences, can be modeled in NOV-4. Information content, provision and consumption aspects in NCO have to be explicitly modeled to describe and analyze the level of semantic interoperability. NOV-7 represents an information model that gives an answer to "what we want to know" and "what we want to communicate" [7].

After modeling processes as part of the business architecture, we detected two approaches on modeling services and systems. First we stick to the temporal progress preset by TOGAF identifying and describing required S*ervices* in the form of taxonomies (NSOV-1) and "Service Definitions" (NSOV-2). Additionally, the orchestration (NSOV-4) and decomposition (NSOV-6) support the classification, structuring and dynamic behavior of respective services promoting interoperability in various domains and on different layers. In NSOV-3, *Services* can directly be mapped to supported *Capabilities* to show their importance within an operation. Further on, one can map these services, supporting *OperationalActivities* in NOV-5 or model service provision or consumption, by using already existing *Nodes* in NOV-2. As a precondition for this approach, the modeler has to have sound knowledge of NATOs C3 (Consultation, Command and Control) taxonomy perspective [19] to identify required services. To proceed to information system architecture (phase C) it is necessary to define *ServiceFunctions* performed by *Services* in NSOV-5. *ServiceFunctions* are implemented by system functions which can be modeled in NSV-5. However, system functions can be described in subview NSV-4 to impose requirements on applicable systems. Thus, this approach might be adapted to design technological requirements for new technological developments to realize interoperability within NCO.

Another approach – departing from the TOGAF methodology presented in Table I – might be suitable to examine the application of already featured systems to realize the required level of interoperability in NCO. In this case, existing systems have to be modeled using a system profile, containing the internal structure or system composition (NSV-1), the system interfaces and communications description (NSV-2) and the already mentioned systems functionality (NSV-4). Additional constraints regarding the systems quality are described in NSV-7. The systems service provision can then be modeled by applying NSV-12 to analyze what services are covered by the application of actual or intended systems. Using system function to operational activity mapping (NSV-5) we can also map the direct realization of *OperationalActivities* by respective system functions and condense system functions to implemented service functions.

Within the technical Architecture, it is possible to examine the feasibility of NCO focusing on the technical and syntactic level of interoperability. For this purpose required resource interactions can be described as a matrix in NSV-3. Furthermore, the data exchange between systems is part of NSV-6. The systems data model (NSV-11) follows the information modeled in NOV-7 (Information Model). Thus, information can be used as an input for modeling required logical and physical data models gaining insights of syntactic interoperability. In the end, technical requirements according technical interoperability are part of the NTV in phase D and E of the ADM.

While compiling the architecture, the development is documented in NAV-1; thus, conventions and recommendations can directly be noted. Additionally, a glossary can be implemented in NAV-2 to put the architecture across.

V. Analyzing Models of NCOs

The model developed in Section IV contains various architecture elements, which are able to be analyzed subview-by-subview or within the architectural context of elements (compare Figure 4). Both variants are capable of examining interoperable processes and technologies of a certain organization to estimate the feasibility of NCOs.

The product-by-product (or subview-by-subview) analysis to examine the different layers of interoperability within the scope of the LCIM is already part of Section IV. The aim of this section is to show several methods to analyze the architecture model as a whole to obtain insights about potentialities, risks, problems and development needs.

SPARX EA's option "*Traceability*" offers an important tool for the cognition of coherences and navigation within the model by revealing all relations with reference to a special element. Thus, this tool significantly facilitates the analysis of the model.

A selection of methods for analyzing an Enterprise Architecture is introduced as followed:

- **Bottom-up analysis**: Starting from the bottom of a tree of elements (ordinarily technical standards defined within the NTV) one can trace the path till the overarching enterprise vision or capabilities. The aim is to obtain knowledge about the importance or redundancy of bottom elements. Thus, you can support decisions about discarding or developing respective technologies or standards.
- **Top-down analysis**: In contrast to the bottom-up approach the top-down analysis starts the examination beginning at the top of the tree of elements (ordinarily capability-based elements within the NCV) and ending at the bottom. The aim is to show effects of cancelling capabilities, which might be obsolete or no longer required, on processes, services and technical systems. Thus, evaluations about savings on the cost of redundant systems and technologies can be done.
- **Risk analysis**: The risk analysis is an important method within in the field of quality management to

systematically identify and assess risks inside processes, organizations or systems. The aim is to find bottlenecks or precarious systems and to validate whose outage. Thus, one can estimate which processes and/or capabilities are influenced by the failure of respective elements and how large a potential risk might be. Furthermore, requirements for the development of new technologies or for redundant systems to minimize respective risks can be imposed.

- **Hotspots analysis**: Comparable with the risk analysis, the hotspots analysis is able to identify and assess elements with major impact on the whole model and thus on the whole enterprise. Hotspots are e.g. single systems, whose functions are accessed by many other systems, or e.g. pervasive technologies. The result of identified hotspots might be the creation or development of redundant systems to improve the distribution of respective system functionalities and the imparting of knowledge about these hotspots.
- **Migration analysis**: Especially in SOA, the migration of services and service functions is very important to apply changes in architectures. The migration analysis supports System Modernization through the identification of dependencies between elements and the reuse of legacy systems [20]. Thus, expenses on the development of technologies can be minimized by providing identified service functions through the usage of existing systems. Migration analysis requires an actual and a target architecture.
- **Capability gap analysis**: The examination of the feasibility of NCOs needs to focus on the covering of required capabilities. The capability gap analysis supports the identification of missing links in the realization of respective capabilities. Thus, required processes, services and/or systems can be recognized in detail and advancements of new technologies can be brought into better alignment to cover needed functions and capabilities.
- **Service composition analysis**: Modularity is one major advantage of SOA. The development of new services can be expedited and improved by analyzing existing and realized services and service functions. Thus, the composition of service functions or parts of other services can generate adjusted services that are automatically related to respective processes and realizing systems.

VI. LESSONS LEARNED FROM ARCHITECTURAL MODELING

There are various problems that can occur in the course of applying enterprise architecture to a particular problem. This section presents some best practice hints and lessons learned, obtained while modeling enterprise architectures to minimize problems in projecting, targeting and performing.

Especially for modeling NCOs it is recommended to apply an architecture model on performed military and/or tabletop exercises. Architects should also take part in this exercise as observers to get a better comprehension of the issue and the opportunity to undertake interviews with Subject Matter Experts (SME). Thus, perceptions and recommendations can directly be included into the model.

The principal investigator of an architectural project is responsible to impose a distinct problem whose resolving shall be supported by architecture products. The issue and the focus have to be precisely and unambiguously defined [7]. Thus, no universal models shall be commissioned. The level of detail with respect to time horizon has to be adjusted too. It is also necessary to provide required and common resources and continuous support by all stakeholders and experts. Reliable architecture modeling should be a result of teamwork requiring a permanent communication between all involved parties, e.g. within workshops.

Methodology specialists are responsible for quality assurance of architecture products. Thus, a constant and intensive support and a quality assurance plan have to be established [7]. Quality requirements for architecture views are e.g. comprehensibility, comparability, consistency and reusability. To ensure content-related and formal requirements it is recommended to adjust the model to the common architecture landscape. This can be realized by establishing and providing an architecture repository or database as well as documenting common architecture conventions for model diagrams and matrices without limiting specific requirements. Conventions should bindingly regulate as much as necessary, but as little as possible. Additionally, architecture repositories should be configured and administered to ensure its quality. Therefore, a central administration has to be responsible for importing, exporting and deleting architecture elements, providing products and applying user and roles concepts to manage access privileges.

According to the iterative character of TOGAFs ADM, the implementation and usage of architecture models have to be carefully planned. Therefore, it is important to familiarize stakeholders that are not acquainted with the method with architecture products by visually editing respective results. Thus, the realization of outcomes can be performed quickly and correctly. Furthermore, architecture models have to be constantly maintained by the architect to populate potential changes and to keep the model up to date.

VII. CONCLUSION AND FUTURE WORK

The feasibility of operations in terms of Network Centric Warfare is dependent on the level of interoperability of the realizing military forces. Today, military missions are frequently performed in a joint and multinational environment, thus, military forces have to adjust their capabilities to the characteristics of NCO.

The LCIM presents a suitable model of the organizations actual and desired interoperability by introducing various layers. The methodology of ADM according to TOGAF combined with the content-related conventions and rules defined in NAFv3.1 are manifested as convenient methods to examine these layers by focusing on different views and therefore, perspectives on the organization.

In this paper, we presented how to use the introduced architectural methods to obtain insights of the organization interoperable capabilities. Layers of interoperability of the LCIM are directly connected to views and subviews of the NAFv3.1 to support the estimation of the feasibility of respective operations. Additionally, analyzing methods have been introduced to assess the actual state relating to the desired condition. It was shown that these methods can be used to focus on special risks and problems as well as to minimize technical and financial effort within the transformation of organization and military forces to develop the capabilities of NCO.

Eventually, risks and problems within the process of architectural modeling have been described and lessons learned together with best practice hints were suggested. These recommendations might help architects and principal investigators to minimize issues while projecting and modeling enterprise architectures.

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