8th International Command and Control
Research and Technology Symposium

Track 1:
Coalition Interoperability

Beyond Technical Interoperability – Introducing a Reference Model for Measures of Merit for Coalition Interoperability

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Abstract

Interoperability on the technical level is a hot topic since several decades. Despite the fact that several technical reference models to increase interoperability have been introduced, we are still waiting for working solutions. The reason may be, that interoperability is definitely not limited to the technical domain but is dependent on organizational aspects as well. To deal with these issues, they have to be perceived first. The recent CCRTS contributed to this very well. To overcome resulting questions, however, the influence must be captured in a reproducible way in form of measures of merit. Based on the experience in several international projects, the author developed a framework to deal with possible measures of merits to be used to deal with the various layers of semantic interoperability in coalition operations.

The paper introduces this reference model, connects it to the recent discussions of measures of merits for C2 Assessment, and introduces some contributions to the discussions of measure for interoperability on various levels. Furthermore, some technical reference models will be mapped to this reference model to show that actual used legacy model results can be migrated, hence reused in this broader context.

1 Introduction

The crux of – or positively stated, the challenge for – the interoperability problem is the advent of Network Centric Warfare (NCW). NCW is about networking humans, organizations, institutions, services, nation, etc., and the related organizational behavior. NCW is not about technical networks; it doesn't focus on technologies. The development of doctrines and guidance for operations using NCW is part of the institutional transformation for the new millennium. While the technical domain is an important enabler, the social components and the processes related to conducting a military operation that will be using the information are as important as the technical ability to interchange the data related to this information.

Furthermore, the relation between technical and operational interoperability is neither proportional nor linear. It is possible that two commanders, who share the same command and control facilities, in particular having the same C4ISR system support, make decisions that are contradictive or sub-optimal. It is also possible that two commanders supported by C4ISR systems that are not interoperable on the technical level are fighting very well together. Therefore, investing in technical interoperability not necessarily leads to an increase in operational interoperability.

These observations motivate the necessity to set up reference model for measure of merits enabling to cope with this in a reproducible manner. In order to cope with these effects, we have to be able to measure them effectively. While the technical reference models (TRM) are only sufficient on the technical level, they can contribute to gaining an understanding how various layers of interoperability can be dealt with. Therefore, two of the TRM in use or under development are presented first to deal with the technical levels. Secondly, some existing measures of merits in use will be evaluated. Thirdly, some technical models being useful to support the analysis of non-technical interoperability issues will be presented. In particular modeling techniques can support dealing with the challenges of operational interoperability. The main idea is the introduction of a Common Operational Model instead of the common operational picture used actually. Finally, the findings will be combined into the proposal for a reference model of interoperability for technical and operational levels.

2 Technical Reference Models

There are many technical reference models in use to determine the interoperability of technical systems. On this level, interoperability is defined as the ability to make use of functionality offered by other components to increase the functionality offered by the own system. Although technical interoperability is not sufficient for coalition interoperability, is facilitates the collaboration if you are able to share information using your C4I systems and other information technology (IT) support.

The IT industry with the support of academia came up with models like the ISO/OSI seven-layer model, which became a standard with general networked IT solutions. Based on such layered approaches, which are used to define various protocols enabling interoperable sharing of information in IT systems, the military community defined their reference models as well. In the light of coalition interoperability, two models will be evaluated further, namely the “Level of Information Systems Interoperability” model (LISI), and the NATO C3 Technical Architecture (NC3TA) Reference Model for Interoperability (NMI).

2.1 Level of Information System Interoperability LISI

The LISI model [1] provides a reasonable framework to scope the needed level of connectivity in the domain of technical interoperability. LISI is established by the U.S. DoD C4SIR Framework Architecture [2]. As depicted in Figure 1, LISI identifies four domains:

- Procedures and Policy,
- Applications,
- Data, and
- Infrastructure

Every one of the PAID domain impacts on information exchange, in other words, a level of interoperability exists within each of the PAID domains.

LEVEL (Environment)			Procedures	Applications	Infrastructure	Data
Enterprise Level (Universal)	4	c	Multi-National Enterprises	Interactive (cross applications)	Multi-Dimensional Topologies	Cross-Enterprise Models
		b	Federal Enterprise			
		a	DoD Enterprise	Full Object Cut & Paste		Enterprise Model
Domain Level (Integrated)	3	c	Domain Service/Agency Doctrine, Procedures, Training, etc.	Shared Data (Situation Displays Direct DB Exchanges)	WAN	DBMS
		b		Group Collaboration (White Boards, VTC)		Domain Models
		a		Full Text Cut and Paste		
Functional Level (Distributed)	2	c	Common Operating Environment (DII-COE Level 5) Compliance	Web Browser	LAN	Program Models and Advanced Data Formats
		b		Basic Operations (Documents, Maps, Briefings, Pictures Spreadsheets, Data)		
		a	Program Standard Procedures, Training, etc.	Advanced Messaging (Parsers, E-Mail+)	Network	
Connected Level (Peer-to-Peer)	1	d	Standards Compliant (JTA, IEEE)	Basic Messaging (Plain Text, E-mail w/o attachments)	Two Way	Basic Data Formats
		c		Data File Transfer		
		b	Security Profile	Simple Interaction Text Chatter, Voice, Fax, Remote Access, Telemetry)		
		a			One Way	
Isolated Level (Manual)	0	d	Media Exchange Procedures	N/A	Removable Media	Media Formats
		c	Manual Access Controls — NATO Level 3		Manual Re-entry	Private Data
		b	NATO Level 2			
		a	NATO Level 1			
		o	**No Known Interoperability**			

Figure 1: The Level of Information System Interoperability (LISI) Model

The resulting technical interoperability is measured in five categories:

- Level 0: Isolated (Manual) – Non-connected, use of manual gateways (diskettes, etc.)
- Level 1: Connected (Peer-to-Peer) – Electronic connection; Separate data and applications
- Level 2: Functional (Distributed) – Minimal common Functions; Separate data and applications
- Level 3: Domain (Integrated) – Shared data; "Separate" applications
- Level 4: Enterprise (Universal) – Interactive manipulation; Shared Data and applications

The level 4 is the highest level of technical interoperability, i.e., data is electronically delivered to the Warfighter regardless what access method he uses (from handheld to C4I workstations) and from where he uses this device. He can just plug into the infosphere. The technical vision is also captured in the Global Information Grid (GIG), as envisioned in U.S. DoD Directive 8100.1 [3]. The GIG will be globally interconnected, end-to-end set of information capabilities, associated processes, and personnel for collecting, processing, storing, disseminating and managing information on demand to Warfighters, policy makers, and support personnel. The GIG includes all owned and leased communications and computing systems and services, software (including applications), data, security services, and other associated services necessary to achieve Information Superiority. A more user-oriented view on the various levels of interoperability is given in Figure 2.

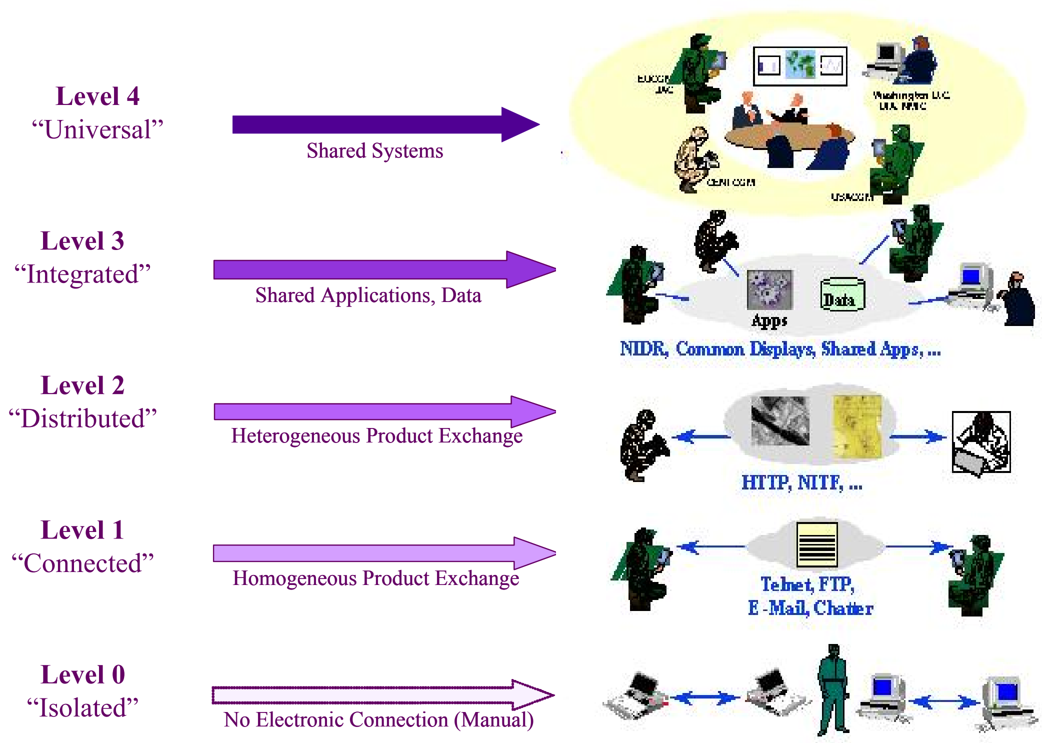

Figure 2: Levels of Interoperability proposed by LISI

The LISI model was successfully applied to deal with identifying issues of technical interoperability not only for C4ISR systems, but also in the domain of C4I-to-M&S interoperability, which is a topic that becomes viable when thinking about embedded training and M&S support to operations. This topic has been extensively dealt with by study groups of the Simulation Interoperability Standards Organizations. Results can be found, among many other special topic papers, in the reports [4] and [5]. A third study group will present the results in Fall 2003 during the Simulation Interoperability Workshop.

2.2 NATO C3 Technical Architecture Reference Model for Interoperability (NMI)

NATO is using a very similar model to LISI. It is comprised in the NATO Consultation, Command and Control (C3) Technical Architecture (NC3TA) [6]. The NC3TA describes the information technology (IT) to be used as a basis for common NATO systems. It addresses architectural descriptions, reference models, and Off-The-Shelf (OTS)-technologies. Furthermore, the NC3TA integrates technical aspects of specific architectures or frameworks such as the NATO Information Security Framework.

The NC3TA consists of five volumes:

- Management,
- Architectural Models and Description,
- Base Standards and Profiles,
- NC3 Common Standards Profile (CSP),
- NC3 Common Operating Environment (COE).

The NC3TA contains five technical reference models of interest to our review of C4ISR/M&S interoperability:

- The ***NC3TA Technical Reference Model*** (NTRM) provides the conceptual framework and common vocabulary for addressing interoperability and compatibility among NATO information systems. It sets a foundation for all NC3 technical architectures.

- The ***NATO Common Operating Environment*** (NCOE) Component Model (NCM) instantiates the NTRM and models the NCOE architecture. In turn, the NCOE aspires to define a plug and play client/server environment [Volume 5] to increase interoperability, reusability, portability, and operational capability while reducing development time, technical obsolescence, training requirements, and life cycle cost.

- The ***NATO-Common-Funded (NCF) Reference Models for Functional Configurations*** (NFC) refines the NCM. This set of reference models provides functional configurations as building blocks for developing the functional architecture of NCF systems.

- The ***NATO Reference Model for Open Systems Information Interchange*** (NOSI) focuses on communications issues not covered by previous models.

- The ***NC3TA Reference Model for Interoperability*** (NMI) models technical interoperability by leveraging the concept of degrees of interoperability.

Categories of elementary services form a descriptive basis for functional interoperability profiles.

In the rest of this section, we will focus the evaluation on the NMI only. Short descriptions of the other aspects are given in [5] and related documents published by NATO.

The NC3TA reference model for interoperability (NMI) establishes interoperability degrees and sub-degrees. Interoperability degrees define a *maturity model* that captures interoperability sophistication. Interoperability sub-degrees describe a *capability model* that reflects available functionality. These degrees highlight the value of structuring and automating exchange and interpretation of data to enhance operational effectiveness. The NMI provides definitions for interoperability degrees and sub-degrees and presents interoperability profiles. The NMI classifies interoperability at four levels.

- Degree 1: ***Unstructured Data Exchange***
  This level involves the exchange of human-interpretable, unstructured data such as the free text found in operational estimates, analysis, and papers. Sub-degrees are:
  - Network Connectivity,
  - Basic Document Exchange, and
  - Basic Informal Message Exchange.

- Degree 2: ***Structured Data Exchange***
  This level involves the exchange of human-interpretable structured data intended for manual and/or automated handling, but requires manual compilation, receipt, and/or message dispatch. Sub-degrees are:
  - Enhanced Informal Message Exchange,
  - Enhanced Document Exchange,
  - Network Management,
  - Map Overlays/Graphics Exchange,
  - Directory Services,
  - Web Access,
  - Multi-Point Applications, and
  - Data Object Exchange.

- Degree 3: ***Seamless Sharing of Data***
  This level involves automated data sharing within systems based on a common exchange model. Sub-degrees are:
  - Formal Message Exchange,
  - Common Data Exchange,
  - System Management,
  - Secure Systems Management,
  - Security Management, and
  - Real–time Data Exchange.

- Degree 4: ***Seamless Sharing of Information***
  An extension of degree 3, this level establishes universal interpretation of information through cooperative data processing. Sub-degrees are:
  - Common Information Exchange, and
  - Distributed Applications.

Unconnected systems, which would represent the interoperability level of degree zero, are not mentioned in the NATO C3 Technical Architecture. The Seamless Sharing of Information (degree 3) equals the Universal Interoperability Level (level 4) of Enterprise Solutions as envisioned in LISI.

Although these technical interoperability models have been applied successfully in the technical domain, they are limited to the levels of technical interoperability. As pointed out before, coalition interoperability comprises of technical and organizational interoperability aspects. However, instead of reinventing the wheel when thinking about a framework capable of dealing with all aspects of coalition interoperability it is recommended to reflect the findings of technical reference models such as LISI and NMI.

3 Using Technical Reference Models for Non-technical Interoperability Issues

There is even more use to technical reference models than just dealing with technical interoperability issues. In fact, the can enable the efficient exchange of information between participating experts coming from various expert or application domains. They can establish a „common language“ to be used to deal with the issues of interoperability.

To deal with organizational interoperability above the technical interoperability, the domain of data and information has to be lifted up into the domain of knowledge and awareness. As accepted in the MORS community, data in context leads to information, which leads to knowledge about general interrelations, which leads to awareness of what is possible in a given situation. The delivering of data and generating of context can be supported by an efficient common operational picture (COP) delivered by an enterprise like distributed C4ISR framework, which is technically interoperable as much as possible. The organizational processes of gaining knowledge from this and having situational awareness can hardly be supported by today's C4ISR systems and are truly beyond technical interoperability. However, the scientific modeling process can be used to gain the necessary insights; in other words, the use of models is perceived to be of value and is a necessary step to reach coalition interoperability through organizational interoperability on top of technical interoperability.

3.1 From Common Operational Pictures to Common Models for Operations

The necessity to build models when designing simulation systems is without question, but why is modeling also very important for systems that are designed to support Command, Control, Communications, Computers, Intelligence, Reconnaissance, and Intelligence (C4ISR), in particular when coalition interoperability is required?

When dealing with C4ISR, it is often assumed that we are not dealing with new and experimental processes, that we know the processes and can very well communicate the challenges and solutions, hence we do not need explicit modeling. In addition, it is assumed that the obtaining of necessary information is sufficient to deal with interoperability. However, reality offers another view.

Very few domains of military applications underwent such dramatic changes as C4ISR did. Due to a rapidly changing and challenging environment, highly adaptive processes had to be developed. This happened mostly within the operation itself, as the necessity hasn't been seen before, often by not perceiving the problem in time as a problem that had to be dealt with. The similarity between two military operations is often minimal. New partners and allies from other nations are joining in, all bringing with them their own doctrine and their supporting equipment. New organizations are joining us that do not know how the military decision process is working, and sometimes there is even the fear to be run over by the hierarchically structured and well-organized command chains of the military partner, so confidence building may become an issue. All these developments and observations lead to an increasing necessity to have a model of the C4ISR processes to be used within the coalition at hand that can be used to support the communication between the different partners.

The models can be used to create a better understanding of what the respective sides are normally doing and are capable of doing finally leading to become the basis necessary to create interoperable federated Information Technology (IT) solutions supporting the new process.

In modern coalition based military operations, the Command and Control (C2) process is not limited to the C4ISR elements known from the traditional scenarios of defense operations based on the use of military force. Modern C2 seems to become increasingly challenging and is comparable to the management of a very complex business process. Consequently, IT solutions supporting business managers are at least good idea generators when looking for IT supporting the C2 process and the C4ISR domain. In this context, among the benefits of process modeling are the following ones, which are derived from the benefits of business process modeling as described in [7] and modified to be applicable in the C4ISR context:

1. ***Models help the decision makers to understand the key mechanisms of an existing process.*** A model provides a clear picture of acting entities, roles, relations, and tasks. This is needed to understand the processes of the allies as well as the processes of the non-military partners and vice versa.

2. ***Models act as the basis for creating suitable information systems that support the process.*** The model comprises descriptions of process that can be used to identify necessary support. Furthermore, the sub-processes already supported by IT in the various participating organizations are displayed, including the interfaces of the systems as well as their information capability in the sense of

available information that can be delivered to other systems as well as suitable information that can be computed to deliver new insights. Therefore, the model can serve to place the various existing systems into their place with the federated system of systems supporting the overarching operations and also serves as the requirement driver for additional IT support.

3. ***Models can be used to improve the current structure and operation.*** By creating a common description of the overall operation and participating organizations and supporting systems, redundancies as well as bottlenecks become obvious. Necessary changes can be identified and solutions can be derived and agreed on based on the common model.

4. ***Models show the structure of innovated solutions.*** The model becomes also the basis for a common action plan supporting radical as well as incremental changes. The desired end state and the necessary steps leading from the status quo to this end state are part of the model. The model itself therefore becomes an important management instrument to orchestrate the necessary improvements in parallel and distributed events.

5. ***Models can serve as a basis to evaluate new ideas, to copy other structures, and to evaluate processes used by neutral or hostile entities of the environment in which the operation takes place.*** As the model comprises the necessary detail needed to derive a conceptual or functional model of the mission space, support by Modeling and Simulation (M&S) directly becomes possible. Respective experiments, like for example conducted under the aegis of TRAC for the Army in particular, or under the aegis of USJFCOM J9 for the armed forces in general, can help to evaluate such future concepts. An appropriate model can be used to orchestrate respective efforts and helps to create a common understanding of all participating institutions.

6. ***Models facilitate the identification of potential reuse of existing solutions.*** Although every operation is special and unique, many processes exists that can be supported by standard solutions. Additionally, when using a common model to do so, the identification of processes having been supported in other operations and that can be modified easily to support the actual process becomes feasible with minimal effort.

This excursus should emphasize the potential contributions of models to deal with interoperability above the information level. If all participants share the same model of the operation, this model can be used to map the supporting IT processes even if the underlying IT systems are not technically interoperable on the highest possible level.

Form his experience in various international projects the author concludes that technical reference models dealing with the modeling process are of tremendous value. When choosing the right technical framework to support the modeling of C4ISR relevant processes, a tremendous benefit for the Warfighter being supported can be achieved.

Under the aegis of the Object Model Group (OMG), a commercial consortium comprising over 800 professional IT companies, actually develops the "Model Driven Architecture," which places the modeling process in the center of IT support to gain maximize interoperability and flexibility [9]. The authors assumes that the evaluation of this approach will positively influence the ideas of coalition interoperability and furthermore can drive new requirements and related solutions for future C4ISR systems, which themselves would be beyond actual stovepipe solutions. In particular, the new architecture Global Information Grid (GIG) Enterprise Services (GES) under development by the U.S. Defense Information Systems Agency (DISA) to become the technical backbone of the GIG, and hence enabling technical interoperability for NCW operations, will be influenced by MDA-related developments.

3.2 Using UML for Modeling for Interoperability

The questions remains, which technical framework to support the scientific modeling process to use. In particular in the IT domain, legions of suppliers of technical solutions are involved. However, the IT industry is more and more following standards.

One of the most important developments of recent years within the commercial software development is the broad acceptance of the Unified Modeling Language (UML) as a standard way to describe software solutions. Since having been standardized by the Object Management Group (OMG) in 1997, it has become of interest to management consulting firms, business analysts, system analysts, software developers, and programmers [10]. As already pointed out, it can be seen as the standard for blueprints of software solutions [7]. Over the last years, the UML became something like the *lingua franca* for modeling purposes.

For those readers knowing the C4ISR Architecture Framework [2] – or within NATO its counterpart: NATO C3 Systems Architecture Framework [8] – it is worth mentioning that most of the products defined to model the three different views of an architecture – operational view, systems view, and technical view – can be mapped to UML products. This applicability of a common standard facilitates to bridge the gap between the Warfighter and the (C4ISR) system designer. It also shows that the modeling results based on the C4ISR Architecture Framework – and the C4I Support Plans, which are a subset of the former – can be reused in the more general UML environment.

Actually, several groups are working on enhancements of the UML for special application domains. The enhancements will be standardized under aegis of the OMG consortium.

Based on the success story of UML for modeling, the OMG consortium started the Model Driven Architecture (MDA) project. The MDA is based on this idea of meta-modeling. It merges the different OMG standards having been developed and used separately so far into a common view by applying common meta models to them. Without going into details, just a view of these standards that will become part of the MDA should be mentioned: the Extensible Markup Language (XML) and the XML Metadata Interchange specification (XMI), the Unified Modeling Language (UML), middleware solutions supporting CORBA, Sun's Enterprise JavaBeans, or Microsoft's DOTNET, the Common Warehouse Metamodel (CWM), the Meta Object Facility (MOF), and many more. The kernel idea is to use a common stable model, which is language-, vendor- and middleware-neutral. This model must be a meta-model of the concept. The MDA offers concepts for such a model. With such a model in the center, users having adopted the MDA gain the ability to derive code for various sub-levels. Even if the underlying infrastructure shifts over time, the meta-model remains stable and can be used to support various middleware implementations based on multiple languages, vendors, and platforms. To be able to do so, the MDA defines an approach to system specifications that separates the specification of the system functionality from the specification of the platform specific implementation. The following picture shows a high-level view on the MDA.

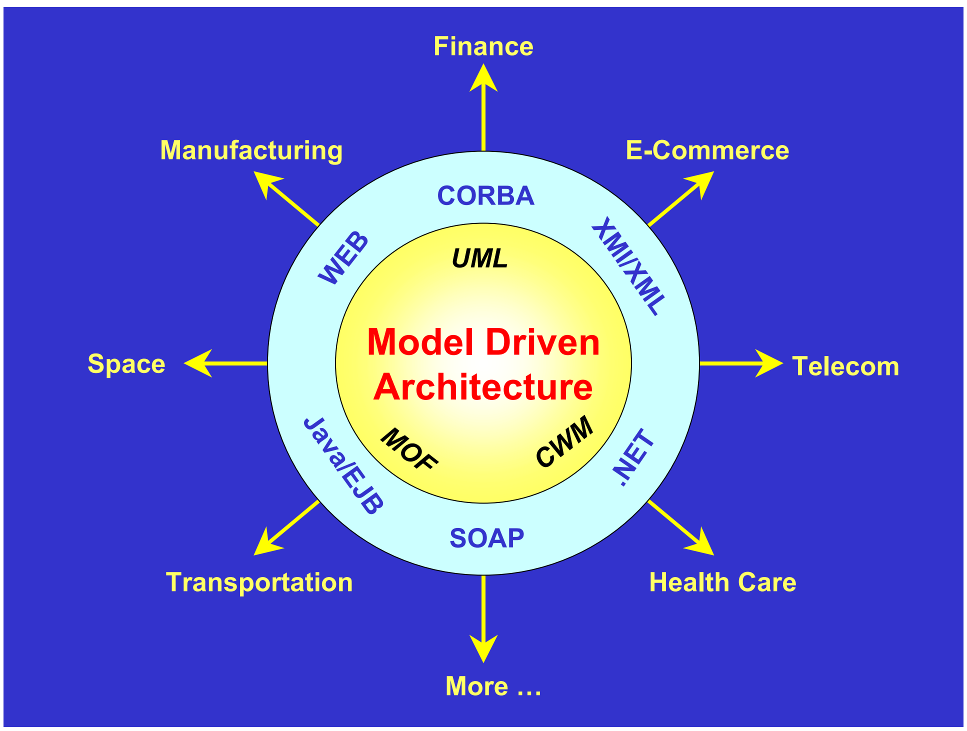

Figure 3: Top-Level View on the Model Driven Architecture

This idea can easily be transferred to coalition interoperability issues. The coalition operation is based on a common model of the operation. This model is supported by various C4ISR systems and procedures (not limited to the IT domain) of the participating coalition partners. The resulting system of systems is than conducting the operation, which itself lies in one of the operation domains. Using this idea, the technical middleware standards (such as CORBA and XML/SOAP) in Figure 3 are replaced by the supporting organizational interpretations (including IT support) to be applied in an operational context.

In summary, the common model of the operation must be the goal of coalition interoperability. C4ISR systems and the related technical interoperability is only a contribution to the overall solution. The author is convinced that C4ISR systems can be improved to support this idea of a "common operational model" instead of a "common operational picture" in particular by integrating M&S systems. However, coping with this related theme in technical detail lies beyond the scope of the paper.

4 Examples for applicable Measure of Merits

The last section motivated that coalition interoperability is based on a common model of the operation, which includes a common interpretation of this model. This section presents some examples of existing metrics and measures of merits. They helped to formulate the proposed reference framework of coalition interoperability and many of the ideas are reflected in the proposal

4.1 NATO Code of Best Practice for C2 Assessment

In 1999, NATO published a first version of a Code of Best Practice (NCOBP) for Command and Control (C2) Assessment that is focused on Article V operations, i.e., the analysis of ground forces at a tactical echelon in mid- to high-intensity conflict. It does not cover the extended mission spectrum of the alliance and the associated issues. Therefore, the NATO Research and Technology Organization (RTO) initiated a follow-on action tasking the expert group SAS-026 to develop a new version of the NCOBP that was to focus on operations other than war (OOTW) and the impact of significantly improved information technology and its implications for military organizations and operations. The resulting revision [11] was published in 2002.

The term C2 is intended to be an umbrella term that encompasses the concepts, issues organizations, activities, processes, and systems associated with the NATO definition. C2 is defined as "the organization, process, procedures, and systems necessary to allow timely political and military decision making and to enable military commanders to direct and control military forces." This definition includes headquarters, facilities, communications, information systems, and sensors & warning installations. Within the NCOBP, military operations beyond the limits of Article V are characterized by multilateral dynamics including interactions not only between friendly and adversary forces but with other actors as well such as, for example, Non-Governmental Organizations (NGO), Private Volunteer Organizations (PVO), International Organizations (IO), international corporations, transnational, sub-national, criminal, and other organizations. In addition, they involve action-reaction dynamics characterized by the impact of interacting soft elements such as culture, morale, doctrine, training, and experience. The revision of the NCOBP represents both, an improvement of the original code based on evidence collected during applications and an extension to account for the new mission spectrum and new information-related capabilities and emphasizing in particular human issues that arise in conjunction with inhomogeneous attributes and diverse motivations of the parties involved. All chapters underwent a complete review. Chapter 5 of the NCOBP is explicitly dealing with Measures of Merits (MoM).

Recognizing the difficulties experienced in C2 assessments in specifying appropriate measures of effectiveness, the 1992 final report of the NATO Research Study Group AC/243 Panel 7 Ad Hoc Working Group (AHWG) on the 'Impact of C3I on the Battlefield' recommended that a hierarchy of measures be established as an important step in understanding overall system effectiveness. This Hierarchy allowed that systems be analyzed at different levels of detail. Similar recommendations have been made by other institutions such as the Military Operations Research Society (MORS). The NCOBP builds on these ideas. With a view to OOTW, an extended hierarchy is proposed to characterize the contribution of military actions to broader policy societal outcomes. The following five levels of MoM have been adopted:

- ***Measures of Policy Effectiveness*** (MoPE) which focus on policy societal outcomes;
- ***Measures of Force Effectiveness*** (MoFE) which focus on how a force performs its mission or the degree to which it meets its objectives;
- ***Measures of C2 Effectiveness*** (MoCE) which focus on the impact of C2 systems within the operational context;
- ***Measures of Performance*** (MoP) which focus on internal system structure, characteristics and behavior; Performance measures of a system may be reduced to measures based on time, accuracy, capacity or a combination that may be interdependent;
- ***Dimensional Parameters*** (DP) that are the properties or characteristics inherent in the physical C2 systems.

In addition to the hierarchy, the NCOBP provides examples and discusses applications of MoM on all levels. It also deals with the question of how to measure MoM and what criteria may be useful for assessing validity, reliability, practicality, and utility of MoM. Table 1 gives some examples for measures of performance (MoP) and measures of C2 effectiveness (MoCE).

While dimensional parameters, measures of performance, and measures of C2 effectiveness can be seen as belonging into the domain of technical interoperability, the measures of force effectiveness and measures of political effectiveness belong into the organizational interoperability section. However, the measure proposed here are mainly used to measure the effect of an operation. Although it can be argued that an operations based on interoperable solutions generally is more effective and more efficient, hence, improving the efficiency can be seen as a hint for higher interoperability, the challenge to deal with various levels of interoperability is only partially met in the NCOBP. Therefore, the MoM hierarchy can be used, but it has to be extended. It has to be ensured that the resulting measures are meeting the criteria for MoM, i.e., validity, reliability, and credibility.

Table 1: Examples for MoP and MoCE (see [11])

MoPs Technical Services Attributes – Hardware and Software	
Availability	Functional capabilities available to users
Survivability	Ability to survive partial destruction of system
Robustness/Endurance	Ability to adapt to environment
Maintainability	Ease of repair or replacement during operation
Computation Capacity	Acceptable response times to users
Portability	Ability to operate on different platforms
Mobility	Ability to move with operational units
MoPs Technical Services – Applications Attributes	
Interoperability	Communications with other C2 systems
Security	Confidentiality and integrity of data
Confidentiality	Information protected at appropriate level
Integrity	Required for confidence of data
Customizability	Ability to customize parameters to actual activities
Quantity of Information	Provide all information required by user
Bandwidth	Ability to support multi-media
MoCEs User Effectiveness – Information Quality	
Selectivity	Ability to provide required information in required amount
Accuracy	The extent to which true values are approached
Comprehension	Facilitate understanding of situation
MoCEs User Effectiveness - Time Related	
Response time	Response to requests within established times
Timeliness	Information available at appropriate time
Ease of use	Ease of access to information
Training time	Time to train users
Decision response time	Time available to commanders

4.2 Code of Best Practice for Experimentation

Very closely related to the NCOBP is the Code of Best Practice for Experimentation (COBPE) [12]. It was developed using the experiences and results gained from the NCOBP related work, but it focuses on the efficiency of transformation experiments. Information age transformation processes are perceived to be highly influenced by technical and organizational – hence also coalition – interoperability issue. It therefore seems to be worthwhile to analyze the sections of the COBPE dealing with measures of merits, i.e., in particular chapter 7 and appendices A and B – a little bit closer. As the NCOBP, the COBPE stresses the necessity that all measures are fulfilling the criteria of validity, reliability, and credibility. Two examples are given in the COBPE that are directly applicable to the problem dealt with in this paper, the Network Centric Warfare Value Chain and the Effects-Oriented Measures and Metrics.

4.2.1 The Network Centric Warfare Value Chain

The Network Centric Warfare value chain approach employs several layered concepts, which can be related to the necessary levels of technical and organizational interoperability:

- The value chain starts with ***Data Quality*** describing the information within the underlying command and control systems.

- ***Information Quality*** tracks the completeness, correctness, currency, consistency, and precision of the data items and information statements available.

- ***Knowledge Quality*** deals with procedural knowledge and information embedded in the command and control system such as templates for adversary forces, assumptions about entities such as ranges and weapons, and doctrinal assumptions, often coded as rules. In future systems, this agile component could be presented by M&S systems. Knowledge quality is the first component related to the common model of the operation.

- Finally, ***Awareness Quality*** measure the degree of using the information and knowledge embedded within the command and control system. Awareness is explicitly placed in the cognitive domain, i.e., definitely above the level of technical interoperability.

Taken together, data, information, knowledge, and awareness can be used to measure the ability to conduct coalition operations, i.e., they can be used to deal with the various levels of interoperability. The technical levels describe the ability to share data, information, knowledge, and awareness. Due to the COBPE, shared information and knowledge can be measured in almost exactly the same way as individual information and knowledge (completeness, correctness, currency, consistency, and precision), but additional dimensions must be considered. Examples for these new dimensions are questions such as

- What fractions of the relevant command and control system users have access?
- What delays may occur in that access?
- How well is the total system informed (what is known to the members)?
- How well the typical (average or median) user is informed?

It becomes obvious that the border between technical and organizational levels is fluent. As stated earlier, a well-informed decision maker may come – due to his cultural background – to a complete different set of decision that his coalition partner using the exact same information based on totally interoperable systems. On the other hand, two culturally similar educated decision makers may use systems that are hardly interoperable, delivering various views on the situation, but may still be able to coordinate their efforts towards a common goal. They overrule, so to say, the technical level of non-interoperability with organizational skills.

In summary, the Network Centric Warfare value chain provides a valuable source to analyze the various layers and levels of interoperability. The MoM hierarchy defined by the NCOBP is explicitly referred to. The symbiosis of NCOBP and COBPE can be directly mapped to the last technical reference model, the metrics for Network Centric Warfare.

4.3 Metrics for Network Centric Warfare

With the introduction of the ideas of Network Centric Warfare (NCW), the ideas of interoperability for coalition operations definitely were leveled above the technical interoperability. In [13], Alberts et al. are proposing the following five level hierarchy of measures:

- Level 1: Measures of Infrastructure Performance
- Level 2: Measures of Battle Sphere Awareness
- Level 3: Measures of Battle Sphere Knowledge
- Level 4: Measures of Exploiting Battle Sphere Knowledge
- Level 5: Measures of Military Utility

Also the human and organizational issues are taking much more into account than it was done before, e.g., by evaluating reaction time, expertise, leadership, motivation, etc. These ideas were reflected in various papers during the recent Command and Control Research and Development Symposia. A very good summary on related proposals was given during a guest lecture at the Virginia Modeling Analysis and Simulation Center (VMASC) in Spring 2003 [14]. The resulting framework in given in Figure 4.

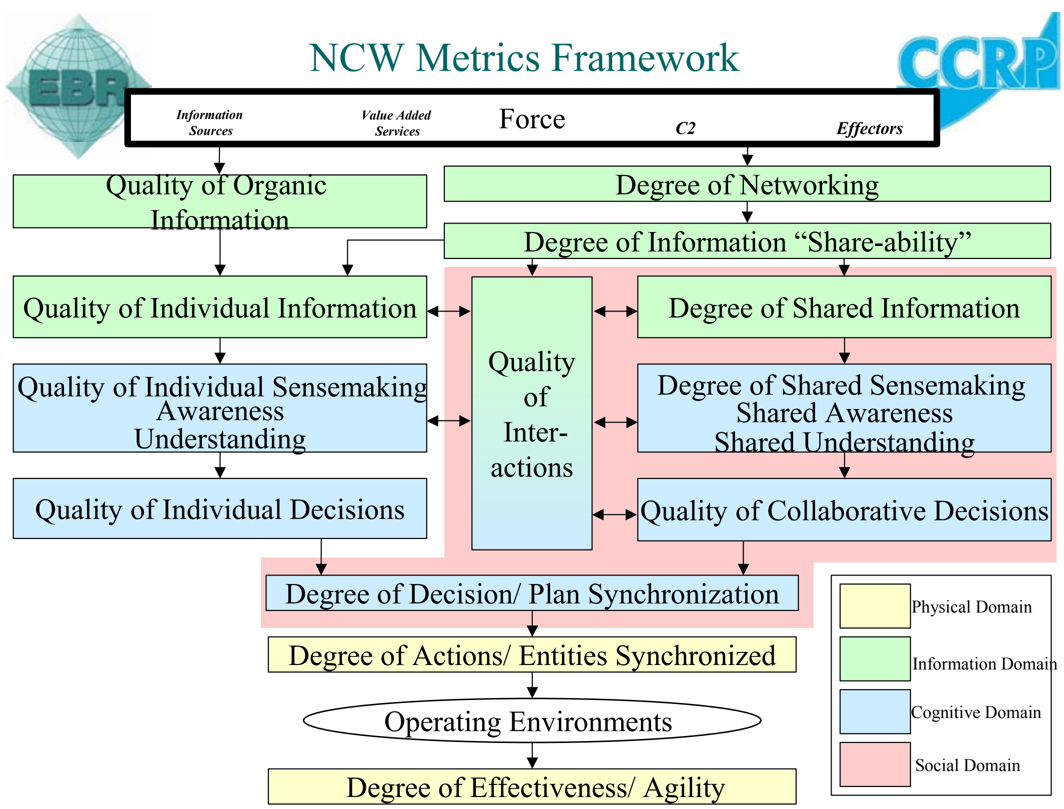

Figure 4: Network Centric Warfare Metrics Framework

We have to distinguish three various domains, namely the physical domain, the cognitive domain, and the information domain. There is a fourth domain mentioned that overlaps and influences parts of the information and cognitive domain: the social domain. The domain can be interpreted as follows:

- The technical backbone collecting, computing, distributing and disseminating the data and producing information is measured by metrics of the information domain. Parts are already affected by human and organizational issues, such as the degree of shared information. These metrics also belong to the social domain.

- The interpretation of the information in the value chain of NCW belongs to the cognitive domain. While some of the metrics are individual metrics, the organizational issues are comprised in the social domain as well.

- Finally, the effects in the battle sphere belong to the physical domain. These are the metrics traditionally used to evaluate the success or failure of military operations.

This framework depicts the interplay of technical and organizational interoperability on the way to coalition interoperability very well. However, as before, the metrics are operation centric, i.e., the various levels of interoperability are still hidden.

5 The Reference Model of Interoperability

To deal with the various levels of interoperability explicitly, the framework shown in Figure 5 is proposed. The author is well aware of the fact that this is just one dimension of coalition interoperability; however, the proposed view helps to facilitate the discussion on technical and organizational support in case of absence of interoperable solutions. It is seen as being complementary to the frameworks dealt with above. It is not intended to be a universal replacement. However, the framework will help to formulate layered models that can gradually be implemented and supported by organizational as well as technical facilitators in a way it wasn't possible before. In particular when looking at the potential support of the C4ISR processes dealing with NCW based on common models of the operations as proposed in section 3.1 and the technical implications presented in section 3.2, this additional view can facilitate the support.

The lower levels deal with the layers of technical interoperability, i.e., the ability to collect, manipulate, distribute, and disseminate data and information. In addition to handling data and information, knowledge presentation in form of procedures and implemented models and awareness support by respective presentation methods is part of the value chain.

The knowledge/awareness layer actually is a fluent transition from technical interoperability supported by the C4ISR systems, such as the GIG, to organizational interoperability layers dealing with the harmonization and coordination of related coalition NCW operations.

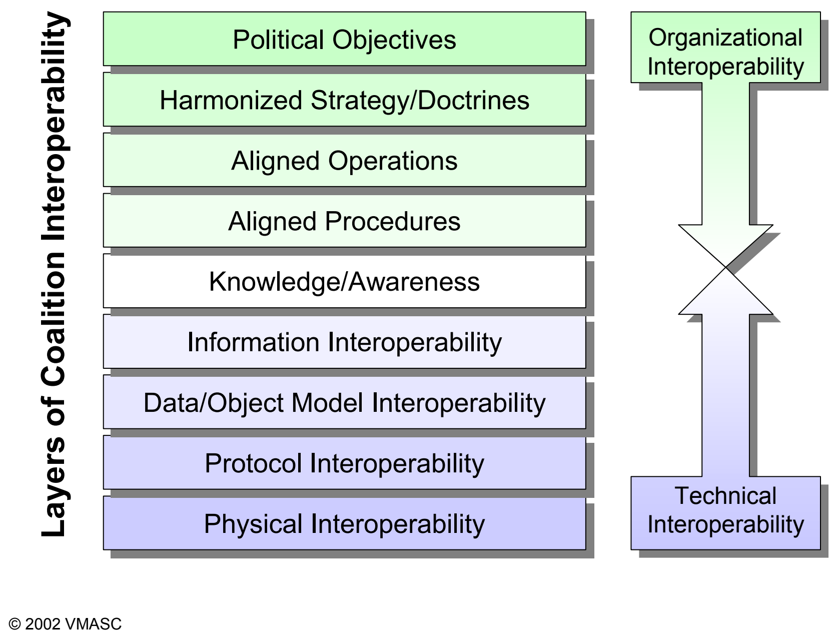

Figure 5: The Layers of Coalition Interoperability

It is obvious that coalition interoperability can be maximized by reaching maximum interoperability ratings on all levels. However, it is not obvious without further evaluation, which of the levels will contribute to what extend to the overall goal of coalition interoperability. In order to find this out, questions as the following ones can have to be answered (grouped by the recommended layers):

- Physical Interoperability
    - Is the system a stand-alone solution?
    - Can a procedure for data/information exchange be established (such as exchange of magnet tapes, disks, etc.)?
    - Is the system physically connected to the C4ISR network?

- Protocol Interoperability
    - What communication protocols are supported on the C4ISR network?
    - What kind of media suitable for data/information exchange can be read and analyzed?

- Data/Object Model Interoperability
    - Are standardized data element used for the data/information exchange?
    - Are (self-) explaining meta data available with the data that allow the mapping of the exchanged data elements to the data elements used in the participating systems?

  - Are Data Management Agencies established that are aware of the data and information presentation of the participating systems?
  - Is the meta data used to describe data and information standardized?

- Information Interoperability
  - Can the procedures and models used to represent dynamical information mapped to each other?
  - Are the cause-effect-chains of the models presenting the information comparable? Can they be harmonized?

- Knowledge/Awareness
  - Is a common operational picture supported?
  - Is the agility of the battle sphere supported, e.g., by supporting M&S routines for courses-of-action analyses?
  - Are collaboration tools and collaborative environments supported, such as workflow management, tele- and videoconferencing, etc?
  - Are various views on the operation supported? Are these views harmonized and coordinated?

- Aligned Procedures
  - Are the Rules-of-Engagements aligned within the tactical levels of the operations?
  - Are the tactics available in the form of military field manuals?
  - Are the field manuals supported by data or knowledge bases?
  - Are models or simulation systems available implementing the tactical procedures?
  - Is a communication infrastructure on the tactical level established?

- Aligned Operations
  - Are the interoperability issues for aligned procedures applicable on the tactical/operational level?
  - Are the military leaders and decision makers aware of the processes of the coalition partners, e.g., through exchange programs of the military academies, cultural and political exchange programs, etc?

- Harmonized Strategy/Doctrines
  - Are the interoperability issues for aligned operations applicable on the strategic level?
  - Are the cultural and social backgrounds of the partners aligned?

- Political Objectives
  - Do the partners share the same political values?
  - Are the ethical backgrounds of the partners aligned?
  - Are the partners aware of the political objectives of the coalition?

To deal with the complete process, the value chain of NCW has to be analyzed as another dimension of the problem. The political effectiveness and the related MoM hierarchy as proposed by the NCOBP is another one. Taken together, this "Cube of NCW Metrics" seems to be more adequate to deal with the challenge than the one-dimensional proposals published so far.

What the author hopes to have shown is the necessity to use models for interoperability solutions. The arguments given in section 3.1 can be applied to every level of interoperability above the physical interoperability. Within the M&S community, the idea starts getting ground that standards for meaningful interoperability must target the modeling level (common conceptual modeling, application of the MDA, behavior description of components as part of the necessary documentation for Base Object Models, etc.). Standards targeting the implementation level are aiming to short. The same thing is true for the C4ISR community. After having focused on common data models and information exchange requirements as the basis for interoperability, meta data and data management are slowly moving into the center of interest. Meta data and data management in the context of dynamical and agile systems is nothing but adding information about the source of data and the context of applicability. This, however, is nothing but connecting the data to an underlying concept – or model – of the operation. The necessary step to support interoperability is to level this meta data activities from the actual basis of often poorly documented "common sense" to a standardized way of conceptual modeling, in other words transforming it from free art to engineering and science.

The only recently released DoD Net-Centric Data Strategy [15] is addressing the issue explicitly in DoD Data Goal 4: "Enable Data to be understandable," i.e., *users and applications can comprehend the data, both structurally and semantically, and readily determine how the data may be used for their specific needs.* This, however, is the goal of the approach described hare as well. The proposed framework is not a solution, but can give some guidance.

6 Summary

The question may arise: What is such a reference model for interoperability beyond technical systems good for? The author perceives it to be very necessary for various reasons, such as

- Using the same reference model, ***various Military Operations Research studies become comparable***. In particular in early stages, the use of standardized methods in research is often perceived to be counterproductive and limited. The result is that such studies often lead to tremendously important insights, but they are based on a rigid method. Results are hardly reusable or transferable. Interpretation of the results may lead to misinterpretations and misperceived constraints for a potential follow-on. This is particularly true for coalition interoperations, where technically hardly measurable human and organizational factors are important. The proposed reference framework can facilitate the process of knowledge transfer between the studies as well as the doctrinal developers.

- ***Establishing technical interoperability***, in particular when interoperability comes as an aftermath to system procurement as it is most often the case in the domain of (international) coalitions, is costly and time consuming. Neither time nor money normally can be expected to be available for short-term coalition operations, which become the military reality more often. The proposed framework can help
  - To overcome the shortfalls of technically interoperability by helping to identify organizational means that can increase coalition interoperability in the absence of technical interoperability.
  - To identify when technically interoperability is crucial.

- The same arguments are applicable to – national and coalition specific – ***Procurement*** as well. Legacy systems of one service, which are still in operational use, and systems of other services are rarely harmonized with joint requirements. Using the reference model it will be possible to decide, which systems have to be technically interoperable and what systems can be integrated organizationally as well.

The reference model as proposed in section 5 is still in its infancy state. However, the author perceives that this framework is having the potential to become a hub for future work. It is recommended to use the framework in MORS workshops and future CCRTS meetings to fill it with additional measures of merit, in particular with those who are needed by the decision makers. In this sense, the framework only is a start. It is assumed that the proposed framework has the right balance between giving researchers guidance to communicate their findings and freedom to choose the methods and tools applicable to solve the problem.

In addition, the author hopes that he was able to show that dynamic and agile capabilities are needed to support future military operations. It is therefore recommended to replace the principal of thinking of a "Common Operational Picture" with the vision of a "Common Model of the Operation." Such models can be introduced by integrating M&S services into C4ISR systems, but the details of this idea are going beyond the scope of this paper.

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