Air Force Institute of Technology

Integrity - Service - Excellence

A Survey on Interoperability Measurement

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Outline

- Background
- Introduction
- Interoperability Definitions
- Interoperability Types
- Interoperability Measurement Centers of Gravity
- Interoperability Measurement Models
- Mathematics of Interoperability Measurement
- Conclusion & Areas for Future Work

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Background

- Interoperability has been a topic of concern for at least 30 years
- GAO has told Congress
  - Interoperability has been a “longstanding problem”
  - “Services historically have been unable to communicate effectively among themselves during joint operations”
  - Interoperability failures in “Korea, the Dominican Republic, Vietnam…(and) Grenada”, “Persian Gulf”
  - DoD continues to experience interoperability problems
- Much work has already been done:
  - Military policy created
  - Interoperability defined
  - Types of interoperability identified
  - Frameworks, methods, models, and measures for interoperability created

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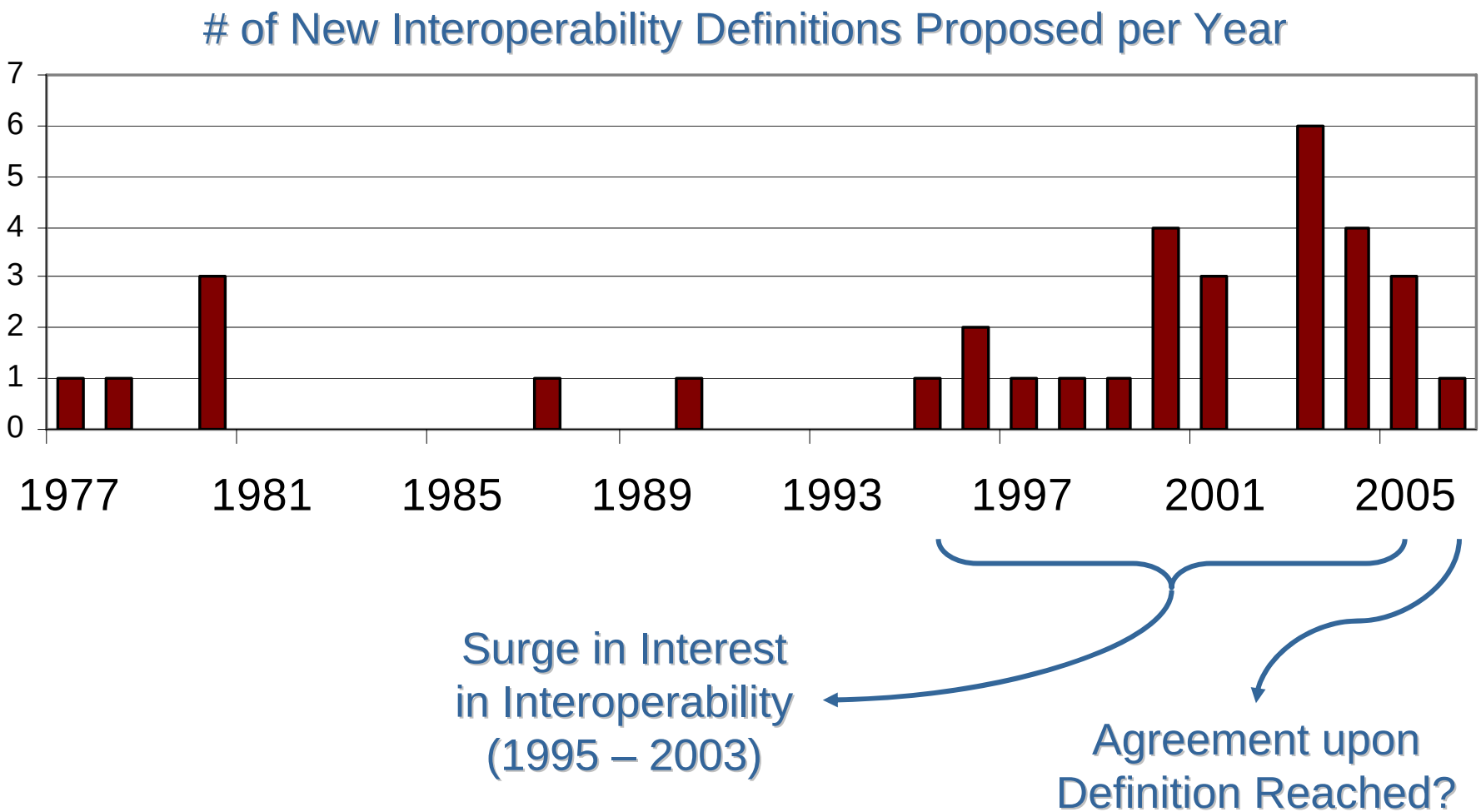
Introduction

- Our paper & presentation are meant to be reference documents
  - Interoperability definitions, types, methods, & centers-of-gravity
- Only highlights of the methods described by the papers surveyed are presented in our ICCRTS paper and presentation
  - Read the original documents for a full understanding!
  - Meticulous bibliography is supplied in the survey paper
- We focused on presenting strengths of the methods surveyed
  - Applicability of each method is limited to its authors' intent
- No one method will be useful in all analytical situations

"Interoperability will never be an analytically useful field of study until it is defined in a quantitative way." (Presson, 1983)

Interoperability Definitions



Interoperability Definitions (cont…)

Most popular definition of interoperability
(13 mentions) of 34 definitions identified was…

"The ability of systems, units, or forces to provide services to and accept services from other systems, units, or forces and to use the services so exchanged to enable them to operate effectively together."

Official DoD Definition (JP1-02): **The ability to operate in synergy in the execution of assigned tasks.**

Interoperability Types

Interoperability Type
Communications
Electronic
Logistics
Peacetime
Systems
Telecommunications
Multidatabase
Specification Level
Object Oriented
High-Level
Procedure Oriented
Semantic
Process
System-to-System
Information
Isolated
Connected
Functional
Domain
Enterprise
Data
Coalition C2

Interoperability Type
Joint
Architecture
Cultural
Technical
Total
Joint Information
Secure-Voice
Non-GIG
"Plug-and-Play"
Coalition
Information Systems
Materiel
Doctrine
Domain-Centered
Mission-Centered
International
Organizational
Flexible
Force
Model
Non-technological

Interoperability Type
Planned
Responsive
Cities
Horizontal
Intra-organisational
Public Administration
Public Service
Vertical
Constructive
Operational
Transitive
Programmatic
System-of-Systems
Conceptual
C4I
Lower-layer
Higher-layer
Application
Product-to-Product
Programmatic
Constructive

Common Interoperability Types

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Interoperability Centers of Gravity

MITRE

DISA
Defense Information Systems Agency
Department of Defense

[dstl]

QinetiQ

VMASC
VIRGINIA MODELING, ANALYSIS AND SIMULATION CENTER

SiM
SYSTEMS INTEGRATION & MANAGEMENT, Inc

UNITED STATES JOINT FORCES COMMAND
USJFCOM

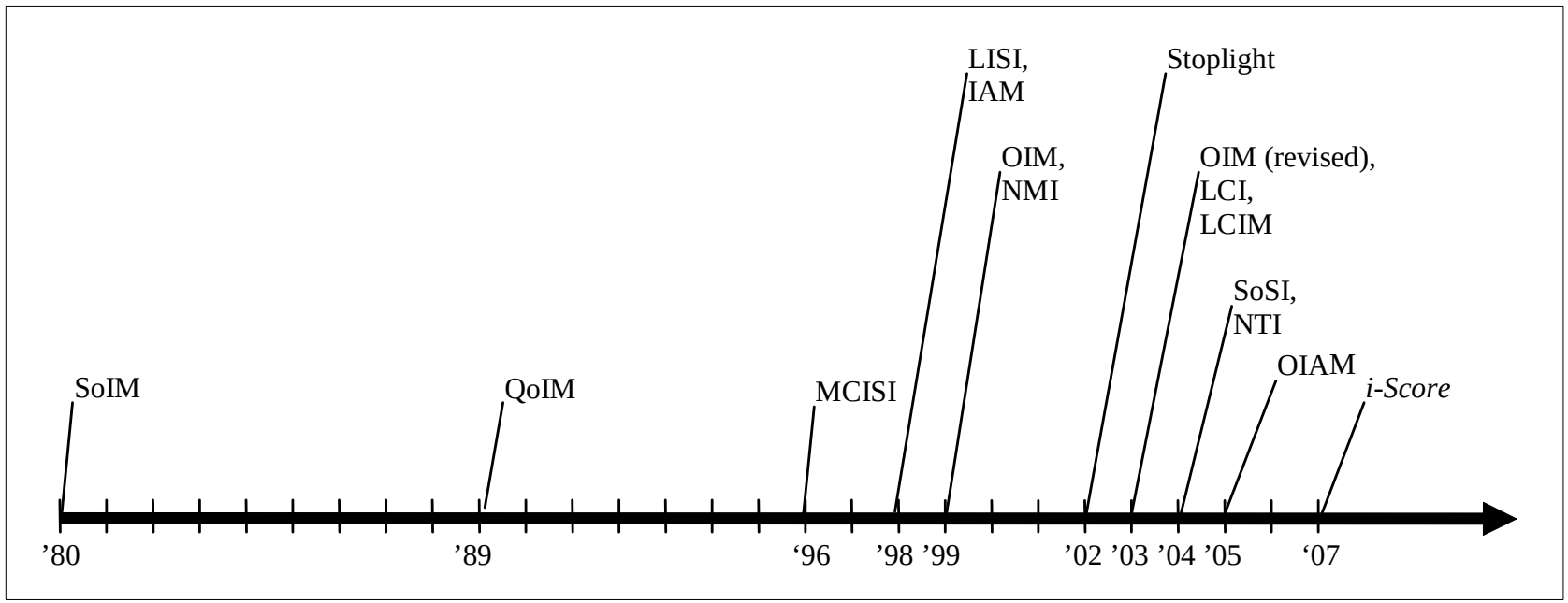
AFIT
AIR FORCE INSTITUTE OF TECHNOLOGY

Australian Government
Department of Defence
Defence Science and Technology Organisation

NATO
OTAN

Software Engineering Institute | Carnegie Mellon

Interoperability Measurement Models



14 Interoperability Models Identified

NOTE: Unless otherwise noted, all quotes and figures presented with each model's summary on the successive slides are attributed to the author of model being summarized.

Interoperability Measurement Model #1

SoIM

Interoperability in Defense Communications, *IEEE Trans. Comm*., 1980
Gilbert E. LaVean

Type of Interoperability: Communication System

Motivation: Addresses interoperability between communications systems supporting U.S. DoD, U.S. Civil Government, and Allies.

Abstract: "A *spectrum of interoperability* is presented that permits system objectives to be stated in more precise terms and also provides a basis for cost versus benefit analysis."

Contribution: Possibly first to recognize and describe *levels* of interoperability—1) separate systems, 2) shared resources, 3) gateways, 4) multiple entry points, 5) conformal/compatible systems, 6) completely interoperable systems, and 7) same system.

Interoperability Measurement Model #2

QoIM

The Quantification of Interoperability, *Naval Engineers Journal*, 1989
Dennis R. Mensh, Robert S. Kite, & Paul H. Darby

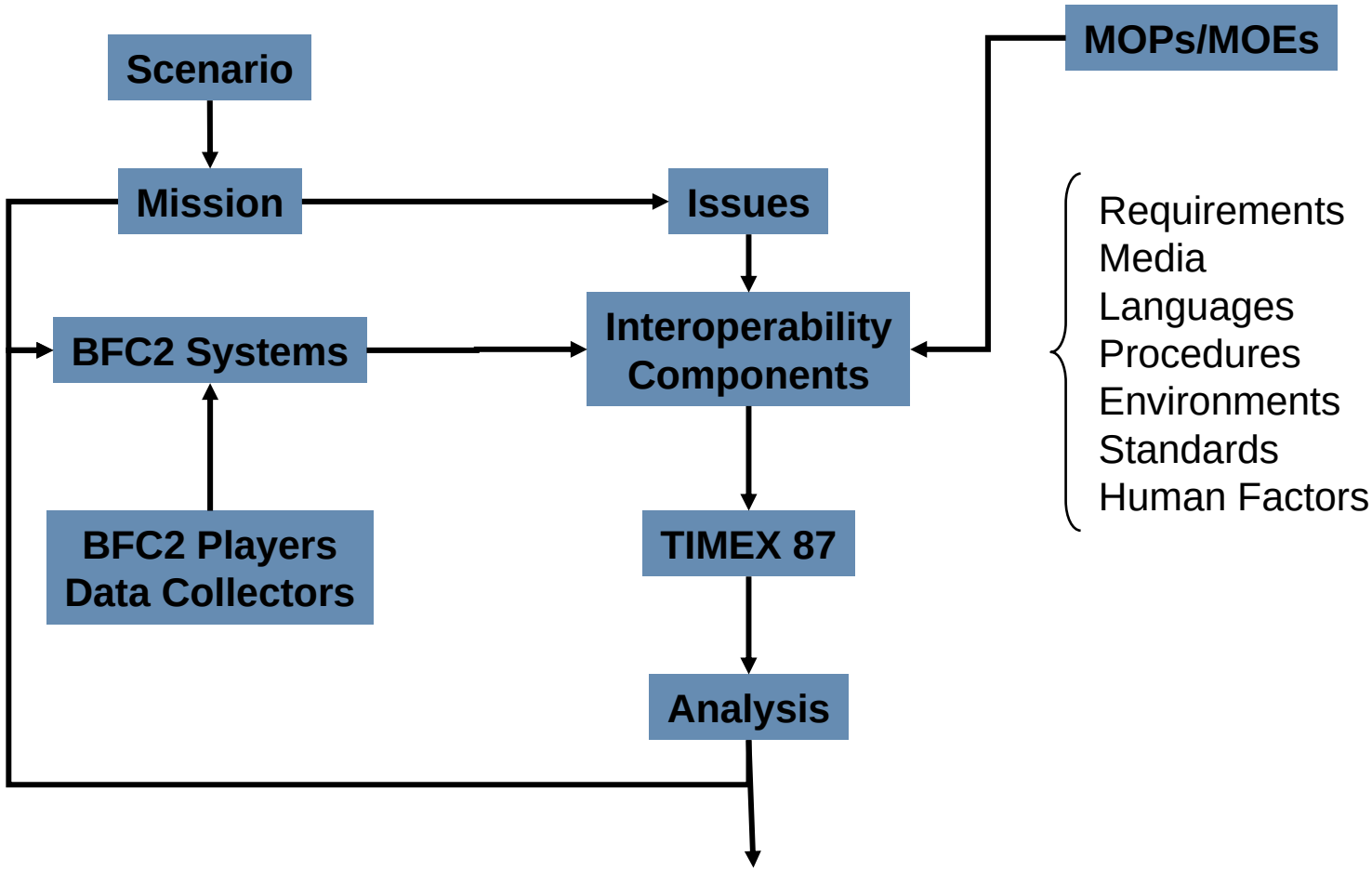
Type of Interoperability: Battle Force C3 Systems, Units, & Forces

Motivation: Joint Pub 1

Abstract: Provides "an analysis tool to enable specific detailed analysis of the interoperability of BFC3 systems, units, or forces for the purpose of uncovering and resolving interoperability issues and problems in the U.S. Navy, Joint, and Allied arenas."

Contribution: Possibly first to define *components* of interoperability to capture the "totality" of interoperability; attached MOEs in the form of logic equations to each component in order to perform interoperability analysis of Battle Force C3 systems using actual exercise data.

QoIM


Scenario
Mission
Issues
MOPs/MOEs
BFC2 Systems
Interoperability Components
Requirements
Media
Languages
Procedures
Environments
Standards
Human Factors
BFC2 Players Data Collectors
TIMEX 87
Analysis

Interoperability Measurement Model #3

MCISI

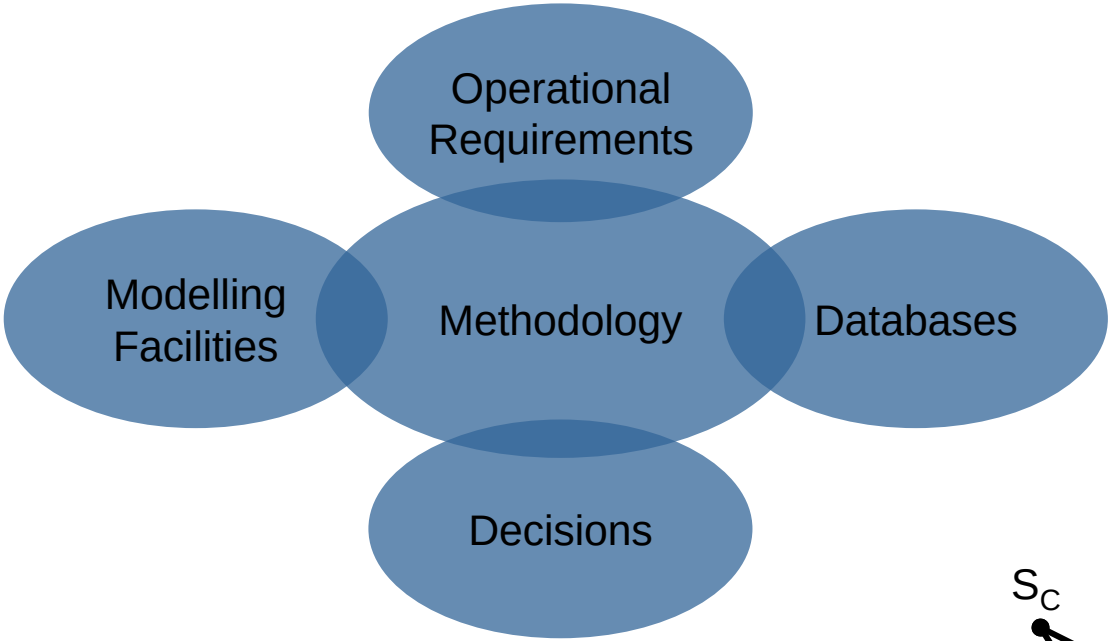
Military Communications & Information Systems Interoperability, *MILCOM*, 1996
Col. Marek Manaowicz & Col. Piotr Gajewski

Type of Interoperability: Military Communication & Information Systems (CIS)

Motivation: Military CIS interoperability between national, multinational, and allied forces are required in support of traditional military C2 as well as in support of international dialogue & cooperation, humanitarian aid, and peacekeeping.

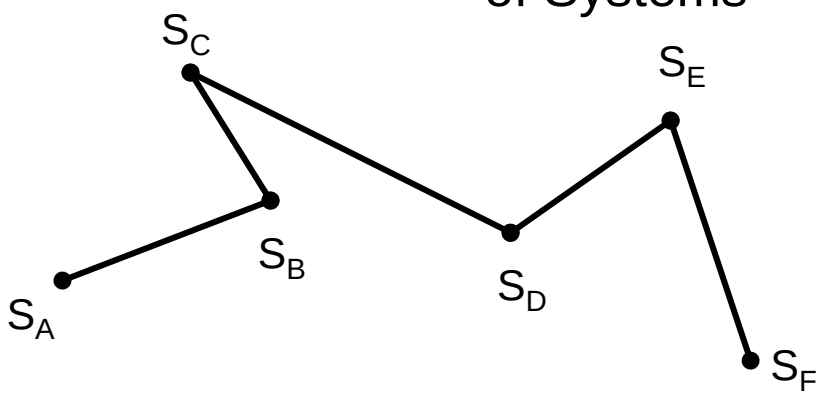
Abstract: General concept of military CIS interoperability modeling is presented.

Contribution: Possibly first to recognize that taxonomic methods are useful and that “great amounts” of data are needed to perform proper interoperability analysis. Also, possibly first to express an interoperability measure as the distance between systems, measured in terms of their “features.” Showed that dendrites can be used to pictorially describe the relationships of CIS systems.



Interoperability Modelling Construct

Dendrite Arrangement of Systems



Interoperability Measurement Model #4

LISI

Levels of Information Systems Interoperability, C4ISR AWG, 1998
C4ISR Architecture Working Group co-chaired by J6 and ASD(C3I)/CISA

Type of Interoperability: Information Systems (IS)

Motivation: Joint Vision 2010 – "speed and accuracy of prioritizing and transferring data brought about by advances in technology."

Abstract: A "practical assessment process for determining the interoperability maturity level or 'metric' of a given system or system pair, and we lack a means for the community to work collaboratively toward achieving higher states of assured Joint interoperability."

Contribution: Possibly first complete reference model for IS interoperability. Defined 5 *levels* of interoperability measured across 4 *attributes*. Described succinct metrics conveying interoperability of a single IS or system pair. LISI institutionalized by DoD in support of JCIDS. Complements DoDAF.

LEVEL (Environment)			Interoperability Attributes: 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	Manual Access Controls: NATO Level 2			
		a	Manual Access Controls: NATO Level 1			
		o	No Known Interoperability			

Interoperability Measurement Model #5

IAM

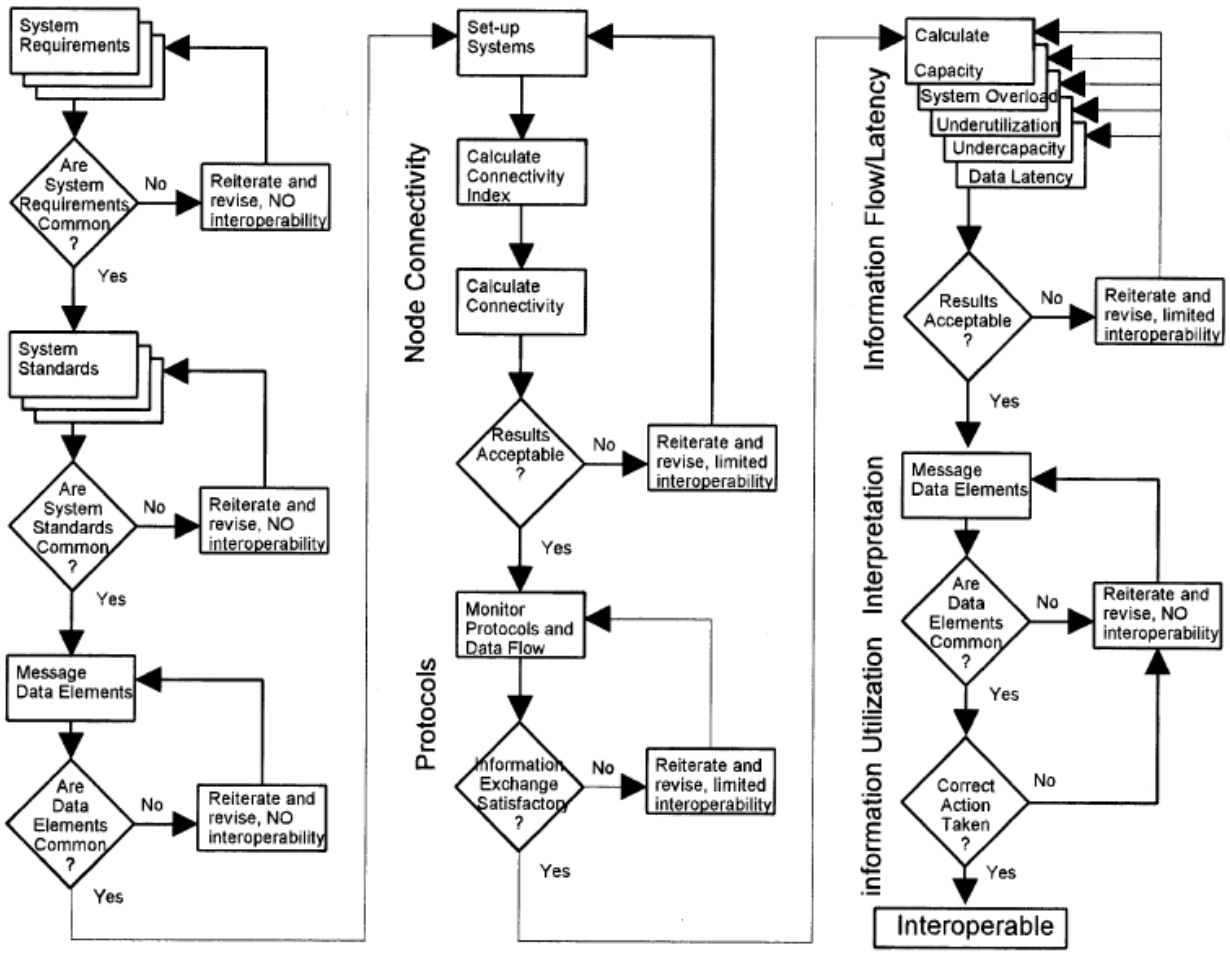
Interoperability Assessment, *Proc. 66th MORS*, 1998 (revised Aug 2003)
Michael J. Leite

Type of Interoperability: System

Motivation: CINCLANTFLT stated in 1998 that "there is no focus on battle group and Joint interoperability."

Abstract: "A methodology that characterizes system interoperability deficiencies through the measurement and quantification of a set of interoperability system components."

Contribution: Defined 7 *degrees* of interoperability and 9 *components* of interoperability. Provided some equations which relate to the 9 components. Possibly the most valuable contribution was a flowcharted interoperability assessment process whose utility was demonstrated by a brief application to a Navy Theater Ballistic Missile Defense case study.


System Requirements
Are System Requirements Common ?
No
Reiterate and revise, NO interoperability
Yes
System Standards
Are System Standards Common ?
No
Reiterate and revise, NO interoperability
Yes
Message Data Elements
Are Data Elements Common ?
No
Reiterate and revise, NO interoperability
Yes
Node Connectivity
Set-up Systems
Calculate Connectivity Index
Calculate Connectivity
Results Acceptable ?
No
Reiterate and revise, limited interoperability
Yes
Protocols
Monitor Protocols and Data Flow
Information Exchange Satisfactory ?
No
Reiterate and revise, limited interoperability
Yes
Information Flow/Latency
Calculate Capacity
System Overload
Underutilization
Undercapacity
Data Latency
Results Acceptable ?
No
Reiterate and revise, limited interoperability
Yes
Interpretation
Message Data Elements
Are Data Elements Common ?
No
Reiterate and revise, NO interoperability
Yes
information Utilization
Correct Action Taken ?
No
Yes
Interoperable

Interoperability Measurement Model #6

OIM

Organisational Interoperability Maturity Model for C2, *Proc. 3rd ICCRTS*, 1999
Thea Clark & Richard Jones

Type of Interoperability: Organizational

Motivation: "The primary challenge of conducting joint operations is increasingly summed up in one word, interoperability." While earlier work focused on system and technical interoperability, this paper addresses "issues associated with interoperability at the organisational level."

Abstract: "Understanding organisational interoperability is…vital for the effective command and control of…task forces."

Contribution: OIM extends LISI to cover organizational interoperability. Like LISI, defines 5 *levels* and 4 *attributes*. OIM updated in 2003 by Suzanne Fewell and Thea Clark and re-published in *Proc. 9th ICCRTS*.

	Preparation	Understanding	Command and co-ordination	Ethos
4 Unified	Completely integrated preparation resulting in normal day to day working. Common doctrine covers all aspects of operations. All other agreements are in place. High levels of integrated training and experience using common doctrine, communication and information system, tools and agreed operational processes.	Completely integrated knowledge building. Shared interpretation. Communication and information system capabilities correspond to LISI enterprise level.	Homogeneous command structure with a single chain of command. No difference in command and leadership style.	A high level of commitment to shared goals. Minimal impact of external constraints. Complete trust and respect. Minimal impact from differences in personnel arrangements and organisational culture.
3. Combined	A high level of preparation. Most other agreements are in place. Common doctrine covering most aspects of operations. Moderately high levels of training and experience using common doctrine, communication and information system, tools and agreed operational processes.	High levels of information exchange and integrated knowledge building. Shared interpretation. Communication and information system capabilities correspond to LISI domain level.	One chain of command but with interaction with home organisation. At most, a few minor problems with fitting into the command structure. Minimal differences in command and leadership styles.	A high level of commitment to goals. Little impact from external constraints. High levels of trust and respect. Little impact from differences in personnel arrangements and organisational culture.
2. Collaborative coalition)	General doctrine in place. Some formal and informal agreements. Some combined training and experience.	Sharing of information and knowledge restricted to specific topics. Some shared interpretation. Communication and information system capabilities correspond to LISI functional level.	Separate reporting lines of responsibility overlaid with a single command chain. At most, a few major problems with fitting into the command structure. May be some differences in command and leadership styles.	Shared purpose. Moderate level of commitment to goals. At most, a few moderate impacts from external sources. Moderate levels of trust and respect. A few impacts from differences in personnel arrangements and organisational culture.
1. Cooperative	General guidelines in place. Some informal agreements in place. Limited combined training and experience.	Exchange of information restricted. Little shared interpretation. Communication and information system capabilities correspond to LISI connected level.	Separate reporting lines of responsibility. Co-ordination only at the highest levels. Significant differences in command and leader ship styles.	Shared purpose. Some major impacts from differences in personnel and organisational culture.
0 .Independent	Almost no preparation.	Almost no exchange of information. Communication and information system capabilities correspond to LISI isolated level.	Separate command structures with little interaction. Major differences in command and leadership styles.	Limited shared purpose. Minimal trust and respect. Some major impacts from differences in personnel and organisational culture.

Interoperability Measurement Model #7

NMI

NATO C3 Technical Architecture Reference Model for Interoperability, 1999, 2003
NATO Consultation, Command, and Control Agency (NC3A)

Type of Interoperability: Technical, Data

Motivation: "To establish measures of merit to evaluate the degree of interoperability between two existing systems by applying standard means." (Tolk & Muguira)

Abstract: "Enhancing operational effectiveness by structuring and automating the exchange and interpretation of data." (Morris, et al.)

Contribution: The original NMI complements LISI by describing 5 *levels* of data interoperability. NMI provides *categories of elementary services* which form a basis of interoperability profiles. According to Morris, et al., NMI was updated in 2003 to "closely reflect the LISI model." NMI is no longer available on-line.

Interoperability Measurement Model #8

Stoplight

An Interoperability Roadmap for C4ISR Legacy Systems, *Acq. Rev. Qtrly*., 2002
John Hamilton, Jerome Rosen, & Paul Summers

Type of Interoperability: C4ISR Legacy System

Motivation: "The DoD has made tremendous interoperability gains…without a way to assess the status of interoperability..it is difficult to quantify this progress…interoperability successes are easily overlooked."

Abstract: "Most systems developed today meet the interoperability requirements …specified in their ORDs…a set of metrics…would highlight the successes of the many agencies that have labored to produce interoperable systems."

Contribution: A simple model which assigns a single color code to a system which indicates how well that system meets operational and acquisition interoperability requirements. Possibly first model to directly address the relationship between requirements and interoperability.

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Stoplight

		Meets Acquisition Requirements?	
		Yes	No
Meets Operational Requirements?	Yes	Green	Yellow
	No	Orange	Red

Interoperability Measurement Model #9

LCI

Beyond Technical Interoperability—Introducing a Reference Model for Measures of Merit for Coalition Interoperability, *Proc. 8th ICCRTS,* 2003
Andreas Tolk

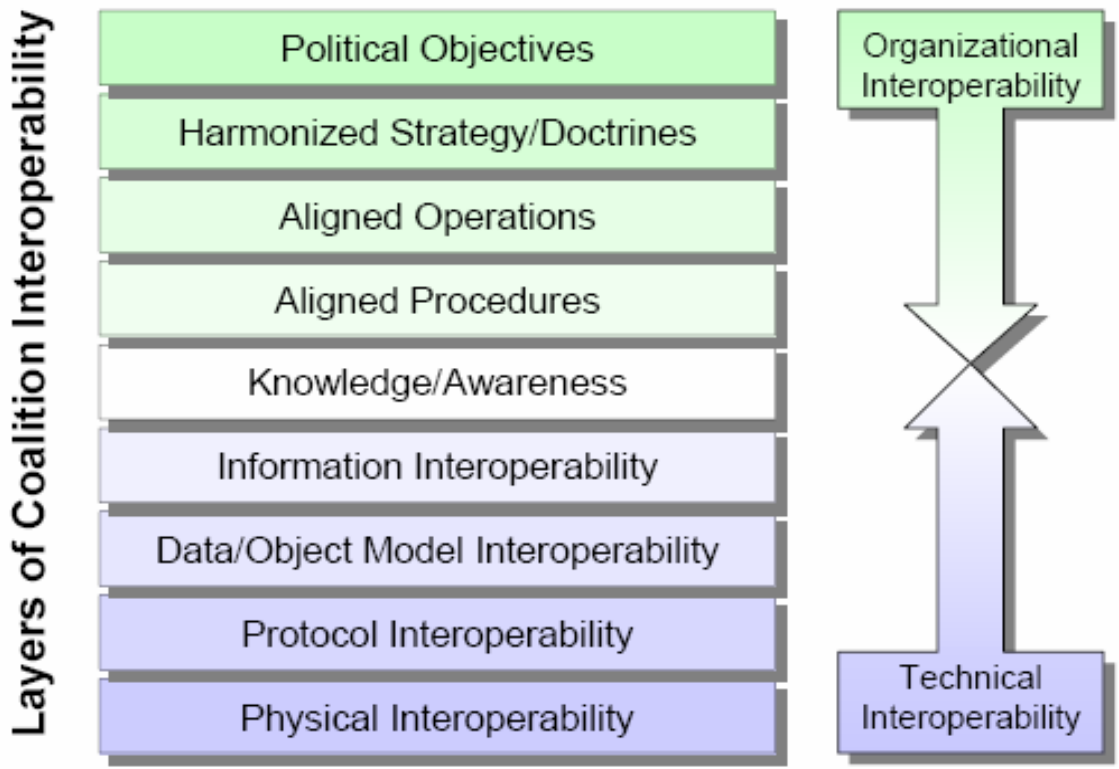
Type of Interoperability: Coalition

Motivation: "Interoperability is definitely not limited to the technical domain, but is dependent on organizational aspects as well."

Abstract: "A framework to deal with possible measures of merit to be used to deal with the various layers of semantic interoperability in coalition operations."

Contribution: Emphasizes the importance of measures of merit in measuring interoperability. Defines a framework of 9 *levels* for measuring interoperability which shows the relationship between organizational and technical interoperability. Describes the continuum between technical and organizational interoperability.

LCI



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Interoperability Measurement Model #10

LCIM

The Levels of Conceptual Interoperability Model, *Proc. 2003 Fall SIW,* 2003
Andreas Tolk & James Muguira

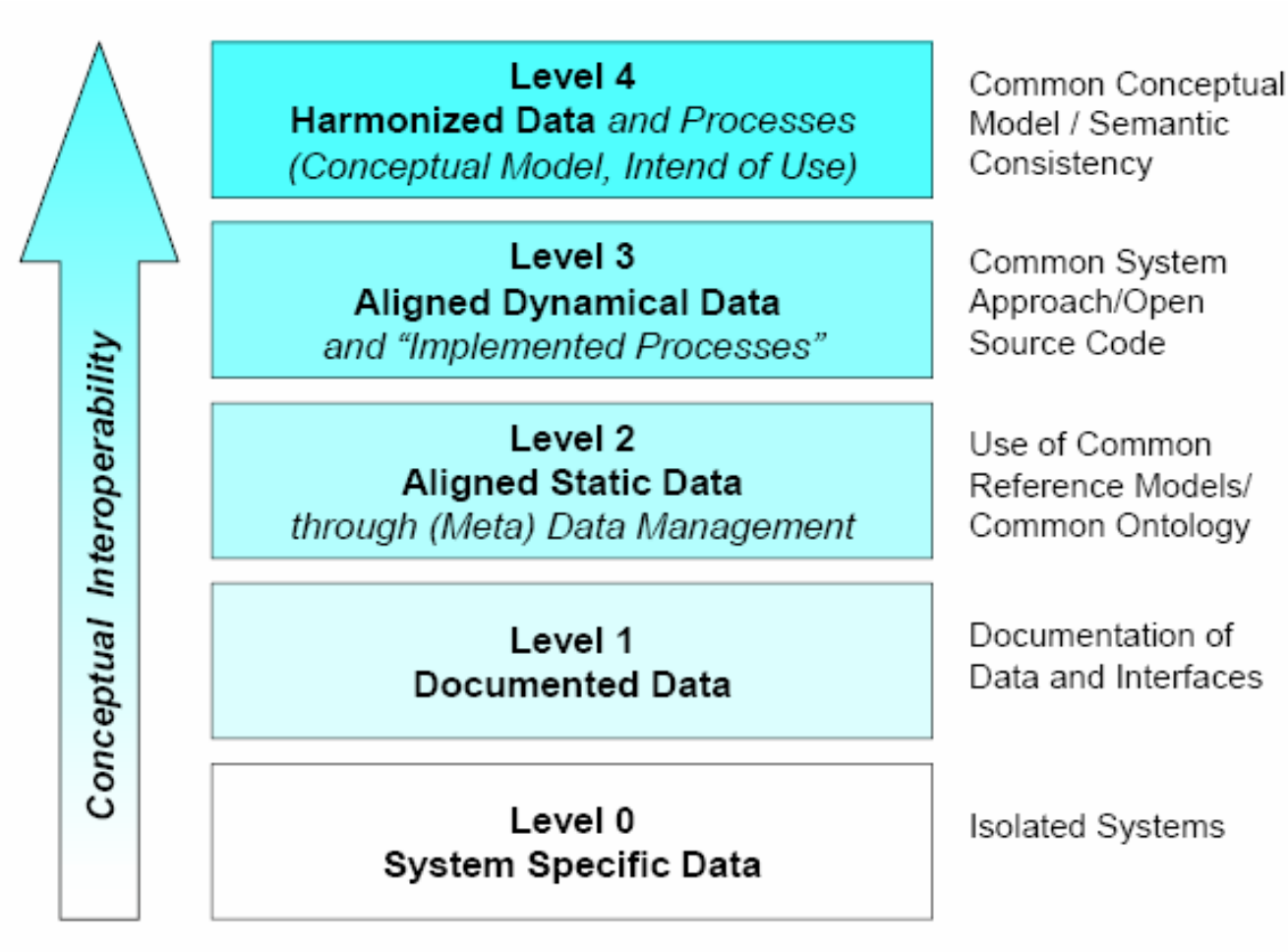
Type of Interoperability: Conceptual

Motivation: "In order to achieve meaningful interoperability of simulation systems on the technical level, composability of the underlying conceptual models is a necessary requirement."

Abstract: "…a general model dealing with various levels of conceptual interoperability that goes beyond the technical reference models."

Contribution: Possibly the first model to "bridge the gap between implementation focused methods and conceptual models." A layered model which enhances the DoD Net-Centric Data Strategy for the Global Information Grid.

LCIM


Conceptual Interoperability
Level 4
Harmonized Data and Processes
(Conceptual Model, Intend of Use)
Common Conceptual Model / Semantic Consistency
Level 3
Aligned Dynamical Data
and "Implemented Processes"
Common System Approach/Open Source Code
Level 2
Aligned Static Data
through (Meta) Data Management
Use of Common Reference Models/ Common Ontology
Level 1
Documented Data
Documentation of Data and Interfaces
Level 0
System Specific Data
Isolated Systems

Interoperability Measurement Model #11

SoSI

System of Systems (SoSI): Final Report, *CMU Tech. Report,* 2004
Edwin Morris, Linda Levine, Craig Meyers, Pat Place, & Dan Plakosh

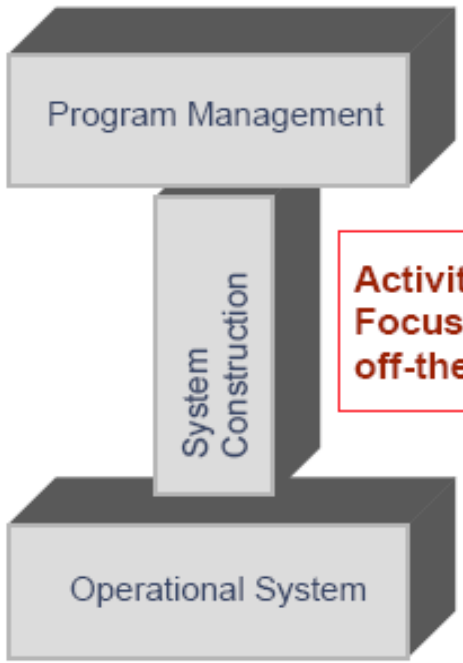
Type of Interoperability: Technical, Operational, Constructive, & Programmatic

Motivation: "Interoperability must occur at multiple levels within and across programs, and not solely in the context of a system construction."

Abstract: "In order to have interoperability between operational systems, one must introduce—and address—the full scope of interoperability between those organizations that participate in the acquisition of systems."

Contribution: Proposed that a set of models is needed to "collectively address all of the dimensions of interoperability." Introduced the concept of an interoperability backplane which includes environmental factors such as policy and standards, especially those prescribed by the program executive officer.

SoSI



Activities performed to manage the acquisition of a system. Focus is on contracts, incentives, and practices such as risk management.

Activities performed to create and sustain a system. Focus is on architecture, standards, and commercial off-the-shelf (COTS) products.

Activities performed to operate a system. Focus is on interactions with other systems and with users.

Interoperability Measurement Model #12

NTI

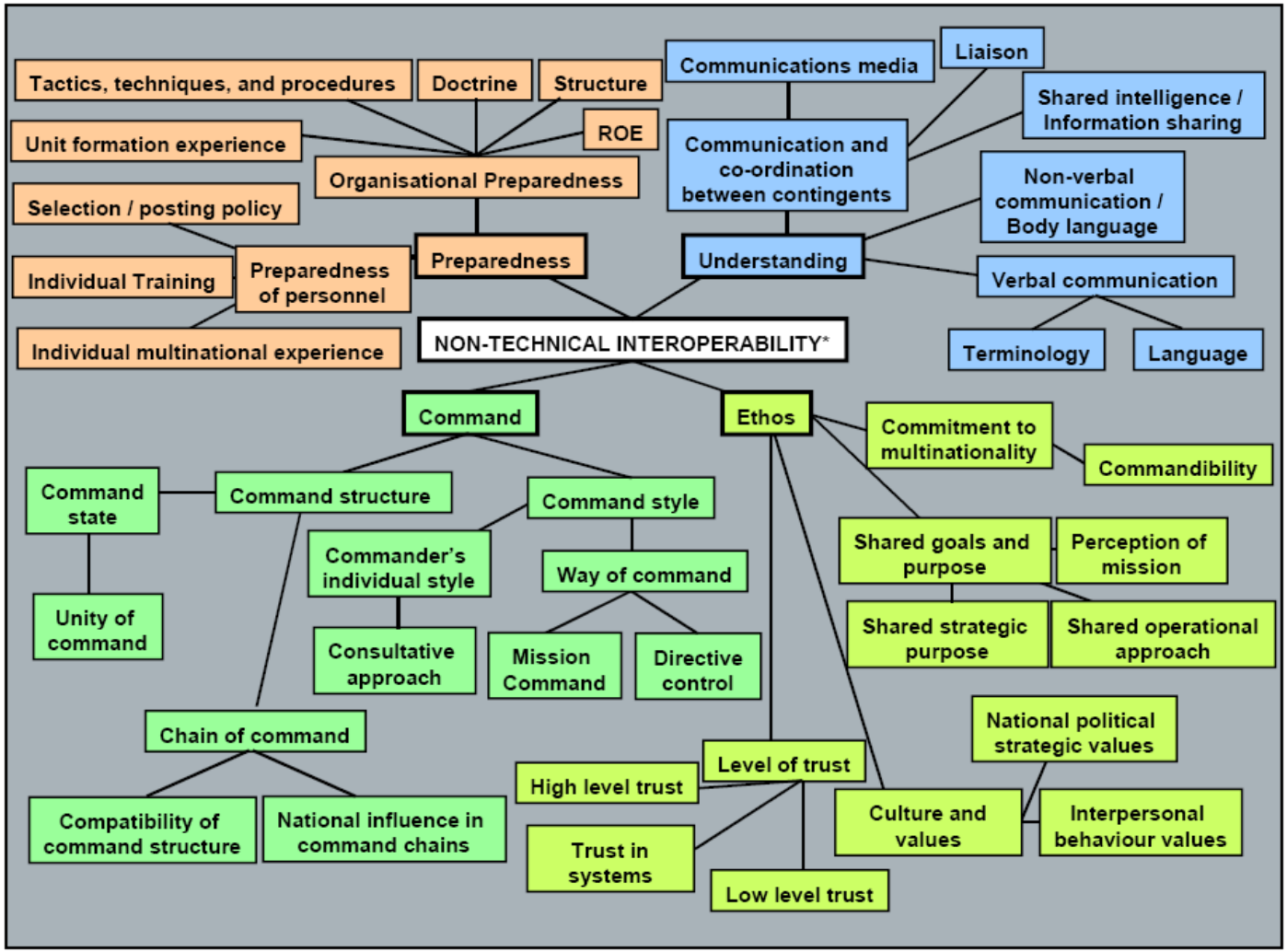
Non-technical Interoperability in Multinational Forces, *Proc. 9th ICCRTS,* 2004
K. Stewart, H. Clarke, P. Goillau, N. Varrall, and M. Widdowson

Type of Interoperability: Non-technical

Motivation: "Interoperability in multinational forces generally refers to compatibility of hardware and software. Connectivity alone, however, does not confer capability and must be accompanied by interoperability of people, process, and organisation."

Abstract: "A valid framework describing factors that underpin NTI."

Contribution: Extends OIM by describing *attributes or factors* of non-technical interoperability, pertaining to multinational forces, largely gleaned from interviews with 45 British officers ranging in rank from Army Captain to three-star general. All had served in multinational operations/settings.


Tactics, techniques, and procedures
Doctrine
Structure
ROE
Unit formation experience
Organisational Preparedness
Selection / posting policy
Individual Training
Preparedness of personnel
Individual multinational experience
Preparedness
Communications media
Liaison
Shared intelligence / Information sharing
Communication and co-ordination between contingents
Non-verbal communication / Body language
Understanding
Verbal communication
Terminology
Language
NON-TECHNICAL INTEROPERABILITY*
Command
Ethos
Commitment to multinationality
Commandibility
Command state
Command structure
Command style
Commander's individual style
Way of command
Unity of command
Consultative approach
Mission Command
Directive control
Shared goals and purpose
Perception of mission
Shared strategic purpose
Shared operational approach
Chain of command
National political strategic values
Level of trust
High level trust
Compatibility of command structure
National influence in command chains
Trust in systems
Low level trust
Culture and values
Interpersonal behaviour values

Interoperability Measurement Model #13

OIAM

An Organisational Interoperability Agility Model, *Proc. 10th ICCRTS,* 2004
Gina Kingston, Suzanne Fewell, & Warren Richer

Type of Interoperability: Organizational

Motivation: "Joint, combined and coalition operations are now the rule. Coalitions are often formed on an ad hoc basis…with partners joining and leaving or scaling their commitments during the course of the…operation." "This requires the development…of modelling and measuring techniques to assess the impact."

Abstract: A model that "aims to capture the dynamic aspects of working in coalitions including the ability of an organisation to contribute to the rapid formation and reformation of coalitions, including novel ones."

Contribution: Possibly first to define a framework for measuring how capable, or agile, an organization is with respect to joining a coalition.

Level	Preparation (includes Understanding)	Command and Coordination	Ethos
4 Dynamic	*Compatible doctrine developed with at least one organisation across each organisational and cultural grouping and the ability to rapidly achieve this with most of the remaining organisations for each activity relevant to the context, and to adjust doctrine during operations.* *Wide variety of relevant collective experience working with other organisations across most organisational and cultural groups within a variety of contexts including for different operational types and cross organisational bodies relevant to the context.* *High awareness of future OI requirements OIA. Able to rapidly plan and train to achieve required OI levels.* *Mechanisms to work together and share information already in place and practiced with at least one organisation across each organisational and social/cultural grouping and the ability to rapidly develop them with other organisations across most organisational groups.*	*Mechanisms for interacting with management/C2 styles with at least one organisation in each organisational group and the ability to rapidly achieve this with most other organisations[2] within the context.* *Practice at timely changing C2 styles. Ability to exploit different C2 styles in different parts of the organisation and to adjust and exploit C2 structures, styles and staffing during operations.* *Ability to staff C2 structures from the whole organisation.*	*Willing to operate with any organisation in the context (including partners with which no formal doctrine has been developed). This includes a willingness to share required information with relevant individuals within most organisational groups and to share information across most information classes in recognition that a common purpose is being served.* *Willing to accommodate organisational differences and with experience negotiating with different organisations.* *Accustomed at adapting to changes in doctrine.* *Willing to accommodate differences in goals and values and with techniques for recognising a common purpose while working with organisations with multiple conflicting goals.*

Level	Preparation (includes Understanding)	Command and Coordination	Ethos
3 Open	*Compatible doctrine/procedures developed with at least one organisation from most organisational and cultural groups i.e. the organisation has multiple sets of doctrine/procedures covering many activities relevant to the context.* *Aware of future OI requirements and have measures and metrics to support OIA.* *Have mechanisms to develop new workable doctrine/procedures with other organisations. Ability to develop doctrine for new activities in advance of operations.* *Considerable variety of relevant collective experience working with other organisations across most organisational and cultural groups.*	*Mechanisms for interacting with management/C2 styles with at least one organisation from most organisational groups.* *Familiarity with different C2 styles and structures. Ability to adjust C2 structures during operations.*	*Willing to operate with most organisations relevant to the context across all of the organisational groups and to share most classes of information with them.* *Willing to adapt to changes in doctrine and procedures. Practiced at gaining new skills. Encouraged to generate alternative mechanisms for interactions.* *Willing to recognising that a common purpose may exist while accommodating differences in goals and values and working with organisations whose goals conflict with each other.*
2 Accommodating	*Preparation for future OI is broadly based, but awareness of future OI requirements is still limited.* *For most activities relevant to the context, compatible doctrine/procedures have been developed with at least one organisation from most organisational and cultural groups i.e. multiple sets of doctrine/procedures have been developed.* *A variety of relevant collective experience working with other organisations across organisational and cultural groups.*	*Mechanisms for interacting with the management/C2 styles of organisations from across some organisational groups.* *Willing to adapt to different C2 styles. Able to adjust C2 structures before operations and C2 staffing during operations.*	*Willing to operate with at least one organisation from most organisational groups and to share some classes of information with them. Encouraged to develop new skills.* *Willing to develop new methods and procedures for interacting with the other organisations.*

Level	Preparation (includes Understanding)	Command and Coordination	Ethos
1 Amenable	*Preparation for future OI is ad-hoc, with limited ability to gather information about future requirements.* *For some activities relevant to the context, there is more than one partner organisation with which at least one set of compatible doctrine/procedures has been developed.* *Limited collective experience working with organisations from other organisational and cultural groups.*	*Acceptance of more than one command and co-ordination style.* *Mechanisms for interacting with more than one management/C2 style.*	*Willing to operate with a limited number of alternative partners e.g. partners without doctrine and to share limited information.* *Willing to adapt to minor changes in doctrine and procedures.* *Only willing to accommodate minor differences in goals and values.*
0 Static	*Almost no awareness of, or planning for, future OI requirements.* *For each activity relevant to the context, there is at most one partner organisation with which a set of compatible doctrine has been developed.* *Almost no collective experience working with any other organisational or cultural group.*	*Only one command and co-ordination style predominantly used and widely accepted.* *Unwilling to accommodate different C2 styles.*	*Not willing to operate with alternative partners e.g. partners with which no formal doctrine has been developed. Unwilling to change organisational structure or practices to accommodate others or share information.* *Generally unwilling to change goals and allegiances and accommodate different values.*

Interoperability Measurement Model #14

i-Score

The Interoperability Score, *Proc. 2007 CSER,* 2007
Thomas Ford, John Colombi, Scott Graham, & David Jacques

Type of Interoperability: Technological, Biological, Organizational, & Environmental

Motivation: In performing network-centric operations, "clearly an important factor is improving interoperability of systems of all types." Extant interoperability measurement methods are "more qualitative than quantitative."

Abstract: "A generalized measure of the interoperability of systems of all types, supporting an operational thread."

Contribution: Possibly the first to define a strictly quantitative means of measuring the interoperability of a heterogeneous network of systems in the context of the operation those systems support. Additionally, proposes a means of defining the maximum measure of interoperability in light of operational and technical constraints.

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Interoperability Measurement Summaries

Method	Measure
Spectrum of Interop., 1980	{1,2,3,4,5,6,7} per system pair
Quantification of Interop., 1989	x/y ratio per component
Mil Comm. & Info Systems Interop., 1996	Pos. integer per system pair
Levels of Info. System Interop., 1998	{G, E, S}⇗{0…4}⇗{a…z} per info system
Interoperability Assessment, 1998	Various number & non-number measures
Organisational Interop., 1999, 2003	(0,1,2,3,4} per organization
NATO Ref. Model for Interop., 1999, 2003	{0,1,2,3,4} per info system
Stoplight, 2002	{R, Y, O, G} per legacy system
Layers of Coalition Interop., 2003	{1,2,3,4,5,6,7,8,9} per coalition
Levels of Conceptual Interop., 2003	{0,1,2,3,4} per model
System of Systems Interop., 2004	User defined
Non-technical Interop., 2004	{1, 2, 4, 8, 12, 16} per attribute per force
Organisational Interop. Agility, 2005	{0,1,2,3,4} per organization
i-Score, 2007	Real number per operational thread

Mathematics of Interoperability Measurement

- Graph Theory
- Optimization Theory
- Probability Theory
- Matrix Methods
- Mathematical Logic
- Complexity Theory
- Metrology
  - Measures of Merit

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Conclusion/Areas for Future Work

1. **Refine the field of interoperability measurement**
   - **“a complete and consistent set of interoperability models” is needed. (Morris et al, 2004)**

2. **Pursue mathematical methods for interoperability measurement**
   - **Qualitative measures are useful, but quantitative methods are required as the next step in interoperability measurement**

3. **A method of measure interoperability of self-forming networks is needed**
   - **OIAM is a starting point**

4. **Perform applied research on extant models**
   - **Necessary to flesh out the strengths and weaknesses of the models**

Questions?

I welcome comments & criticisms!

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