EXPERIMENTATION OF COMPLEX ADAPTIVE AEROSPACE MISSION CAPABILITIES

Research Questionnaire

Sub-problem 3 **Draft V 0.5**

Malcolm G Tutty

System Engineering and Evaluation Centre (SEEC)

School of Electrical and Information Engineering

Building F, Mawson Lakes Campus

University of South Australia

Mawson Lakes, South Australia 5095

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Respondent: _____

Affiliation: _____

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INTRODUCTION

This research questionnaire is designed to investigate a RAAF sponsored sub-problem for a University of South Australia Research Plan of 30 May 2008 and a NATO Research & Technology Organisation (RTO) Technical Activity of April 2009. You will have been supplied a copy of that plan to containing further details of the key themes and background to the research proposed.

The contemporary conventional wisdom is that on the battlefields and battlespaces of the near future our soldiers, sailors and airmen will be presented with ever increasing voluminous and often conflicting data from multiple network capable systems and sources and will face 'cognition overload'. Experimentation and test and evaluation (T&E) in general are major activities during the development and ultimately the validation and verification of such systems during the capability acquisition process to ascertain it's operational suitability and effectiveness. Surprisingly, there is still no accepted international standard (or standards) for T&E or experimentation for today's military systems let alone tomorrows network enabled, complex, adaptive ones. Numerous NATO studies, such as the Air Launch Weapons Integration ALWI-2 (2004), have identified the need to address this situation in numerous disciplines. As the first step to such a standard for networked enabled kill chains, an AGARDograph establishing a Code of Best Practice (CoBP) drawn from national approaches covering modelling and simulation (M&S), and ground / flight test is proposed to address this deficiency (as the first big step to a consensus based standard). While many NATO nations test and operate aircraft using various standards for subsystems, the requirement to conduct flight test validation of joint aerospace capabilities in a network enabled integrated mission environment will become an essential part of the aeronautical engineering skillset of NATO nations. The techniques required to develop, test and certify ever increasingly complex, safety critical systems and/or capabilities will involve unique skills and experience which have not yet been widely disseminated and updated among NATO nations. Thus, it is worth the effort to review the state of the art techniques that have been successfully used on various recent and on-going aircraft flight test programs. Previous work at MIL-HDBK-1763 (1998), Hayes and Alberts Experimentation CoBP (2002), NATO RTO C2 Assessment CoBP (2002) and the more recently published The Technical Cooperation Program GUIDEx (2006), JMETC & JTEM approaches where a tailorable framework is established will be used as a starting point. Such an experimentation CoBP will provide a means for planning, comparing the results, assessing technology readiness consistently and thereby enhancing their reliable use in future research/testing that will be of immediate use to practitioners.

The NATO RTO Systems Concepts and Integration (SCI) Panel have approved the proposed research for development by their Flight Test Technology Team (FT3) of a CoBP AGARDOgraph with participation by all of the key members nations (Australia, Canada, UK, US,....) titled "**Joint Aerospace Integrated Mission Environment Experimentation CoBP".** to follow on from work under SCI 189 for V&V of Network enabled capabilities. The CoBP will be similar in nature of that completed by NATO RTO for C2 Assessment under SCI Research Group SAS 026 and published under the US Command & Control Research Program (DOD CCRP). The NATO RTO M&S group, International T&E Association (ITEA) and the Flight Test Society of Australia (FTSA) have also agreed in principle to seek their members voluntary participation as the perfect international learned societies available to help those nations formally involved with the research and approval of the CoBP. The National Test Pilot School in Mojave, California are also participating to ensure that the methods are appropriate to the next generation of modelling & simulation as well as ground and flight testing.

The fundamental problem this research will seek to answer is:

> ***To what degree can experimentation be used to enhance the confidence in our future network-enabled complex, adaptive, aerospace mission capabilities?***

Overall, the sub-problems used to explore this question with you and other Australian and international subject matter experts are:

- **Sub-problem 1 –** What is the utility of the contemporary capability development and management models that are in use? (Currently due for completion in Dec 2009)

- **Sub-Problem 2** – What is the suitability of contemporary systems engineering, interoperability and experimentation practices for complex, adaptive military aerospace mission system capabilities intending to be network enabled and used with air armament? (Currently due for completion in June 2010)

- **Sub-Problem 3 –** Is a code of best practice that incorporates modelling and simulation into experimentation, modelling & simulation and ground and flight T&E frameworks achievable now that can serve to give operational staff more confidence in the operational utility of network enabled aerospace mission systems? (This document)

- **Sub-Problem 4 –** Determine insight from case studies of the application of this code of best practice and model to real world avionic mission system upgrades and network enabled operational experimentation.

Each Sub-question is explored in an individual questionnaire with Sub-problem 4 being addressed separately using differing research techniques as described in the Research Plan. Interviews with key respondents are also planned prior to formalising a JAIME Experiment6ation CoBP etc.

ETHICS STATEMENT

Collection of data is entirely for the purposes indicated in the cited Research Plan. The data will not be used for any other purposes, nor will data be provided to others in a form that will enable identification of the respondent.

Further details of University of South Australia's ethics criteria may be found at:

http://www.unisa.edu.au/policies/policies/alpha.asp#res check....

Please note that this questionnaire is unclassified and has been drawn from **unclassified, open sources** and are those of the author. They are intended to promote awareness and discussion on the challenges being faced to improve the experimentation of Australia joint forces, major allies and coalition partners as we all transition to network-enabled 'tailored effects' based defence forces.

(Original Signed)

Malcolm G. Tutty MEng, FIE(Aust), FRAeS
PhD Candidate

BACKGROUND TO COMPLEX ADAPTIVE SYSTEMS

While there is no universally agreed definition for a complex system, the term is usually applied to systems with 'many strongly-coupled degrees of freedom', Wikipedia (2007). The term 'system' is highly overused, with it being casually applied to everything from a Home Entertainment System, to the affairs of government of a nation (System of Government) and to the planets orbiting the Sun (Solar System). Added to the mix is the use of adjectives such as 'complicated'[1] (and presumably those that aren't 'simple') and 'complex'[2] often without a definition or description of what is meant. Complicated systems (such as aircraft, ships and vehicles) may be reduced to their parts for both design and analysis purposes so that their behaviour can be predicted to a high degree of certainty. Complexity Science[3] is the emerging field with the promise of providing some fundamental principles and theory for engineering systems subject to such complexity in their patterns of behaviour. It is suggested by Moon (2007) that the salient features of systems displaying such complex behaviour include:

- Interactions that are non-linear and include feedback loops.
- They are open systems where there is a net flow of flux (energy, matter or information) across the system boundaries; although specific boundaries may be difficult to determine and depend on the perspective of the observer.
- There can be nesting where component systems are themselves complex systems. The component systems may be connected so as to a form small-world network with a multiplicity of connections.
- Complex systems display emergent phenomena[4] and have 'memory' in the sense that prior states influence present states (formally they are said to exhibit hysteresis).

Complex adaptive systems (CAS) are special cases of complex systems that are designed to have the capacity to change and 'learn' from experience. Today they are often a form of systems containing many autonomous agents who self-organize in a coevolutionary way to optimise their separate values. Complex systems often use networks that may be seen as being configured for an overall purpose providing services rather than a specific function. They would, ideally, be designed to provide versatility, robustness and potential for growth (ie scalable[5]) rather than optimised for narrow functionality. The research being undertaken must address experimentation of aerospace mission systems[6] in the joint aerospace environment – which does mean interfacing and cooperating[7] with land and maritime environments!

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1 Used to describe an intricate system with many components that each perform specific, usually highly specialised, functions and are designed for operation as part of a larger system: they are not intended to operate as separate, autonomous systems.

2 One not describable by a single rule. Structure exists on many scales whose characteristics are not reducible to only one level of description. Systems that exhibit unexpected features not contained within their specification. Systems with multiple objectives. See http://www.calresco.org/glossary.htm as of 21 Aug 2007

3 The study of the rules governing emergence, the constraints affecting self-organisation and general system dynamics in nonlinear adaptive interacting systems. The study of the collective behaviour of macroscopic collections of interacting units that are endowed with the potential to evolve in time.

4 Those behaviours, features or functionalities that pertain to the network in its totality and cannot be attributed to individual elements. They may be patterns of behaviour, structural features or functionalities arising from the connection of the elements into a network and the subsequent interaction of those elements. Peer-to-peer networking on the Internet is an example of such an emergent phenomenon.

5 The property of a system or network which indicates its propensity to be readily enlarged, physically or functionally. The term is used in telecommunications and software engineering to indicate whether a system's performance can be increased in proportion to the capacity added.

6 Which includes: the air or space vehicles' Data Management System, Navigation, Communication, data links, ground control station, electronic surveillance and warfare systems such as RADAR, Electro-Optic / Infra-red, Acoustics, EWSP, etc **and** the Armament/Ordnance Stores Management / Fire Control Systems.

7 The idea that two agents can increase both their fitnesses by mutual help rather than by competition. This assumes that resources adequate for both exist, or are created by the interaction, and relates to synergy and 'compositional evolution'.

RULES OF ENGAGEMENT FOR THE JAIME CoBP

- The NATO CoBP AGARDograph will cover:
    - Joint network enabled, effects based, aerospace weapon systems
    - the four domains of warfare: physical, information, cognitive, social
    - complex adaptive systems including:
        - sensors
        - command and control as well a promoting the cooperation and collaboration transition
        - force application and air armament as well as directed energy
    - defence experimentation, including all forms of the T&E alphabet soup
    - modelling and simulation
    - ground and flight testing

- As a NATO CoBP for JAIME Experimentation is proposed as one tangible outcome of the research (see Sub-Problem 3) there will need to be formal member nation ratification of the AGARDograph considered as part of the research plan. The candidate proposes to use the successful Joint Ordnance Commanders Group for Aircraft Stores Compatibility approach for consensus based standards to do so. Inputs from academia, industry and defence will be widely sought, collated and used for analyses, review and approval by the national NATO SCI FT3 representatives prior to use of the NATO RTO AGARDOgraph review and publication processes. The implication of this is that any inputs to the CoBP specifically will obviously need to have your national representatives support.

- Information related directly to the research program is also available from the following:
    - Questionnaire see University of SA's website at www unisa.edu.au/.... You can also email any comments directly to TUTMG001@student.unisa.edu.au
    - CoBP AGARDograph see NATO RTO's website at www.nato.rta... You can also email any comments directly to malcolm.tutty@defence.gov.au
    - In both instances you will need to use the Password: Maven99 to view, download or to upload or make changes. Check both can do this ????

- Your national representatives are:
    - AS: WGCDR M.G.Tutty with Dr T Moon, DSTO and XWZ as Service SMEs
    - CA: TBA
    - FR: TBA
    - GE: TBA
    - IT: TBA
    - US: W. Lowry with XYZ lead boffins from AFRL and ONR and USAF: FLTLT S. Bird AFSEO, USN: Mr A. Piranian & USA: M. Johnson as Service SMEs
    - UK: Mr D. Morley with XYZ as dstl and Service SMEs
    - NATO M&S Research Group POC: XYZ
    - US DOD CCRP POC?
    - Contact details are available from the candidate and from the NATO RTO website.

RESEARCH SUBPROBLEM:

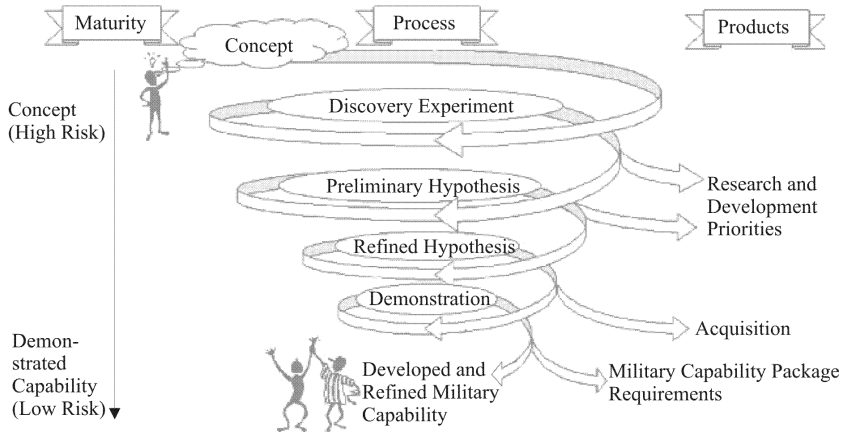
Is a 'code of best practice' that incorporates modelling and simulation into experimentation, modelling & simulation and ground and flight T&E frameworks achievable now that can serve to give operational staff more confidence in the operational utility of network enabled aerospace mission systems?

Key Themes and Implications

The C4ISR Paradigm of C2, Communications and Computers for ISR is now already heading to C2, Cooperate and Collaborate for ISR

ITEA C4ISR in a Joint Test & training Environment, April 2008

Experimental Framework will use CoBP for Experimentation at Hayes & Alberts (2002)



- ***Standard - A description of a process, material, or product meant for repeated use in one of more applications covering: materials, processes, products and services. STANMAN 2002 NATO Focus: Doctrine, Procedures and Equipment***
  - ***ISO Definition & process ???? – is this where we need to be finally???***
  - ***CoBP Definition – CCRP vice NATO RTO ?????***
- ***Interoperability*** **the ability of coalition forces to train, exercise, and operate effectively together, in the execution of assigned missions and task.**
  - **Compatibility - Without causing unacceptable interactions**
  - **Commonality - Same doctrine, procedures, or equipment are used**
  - **Interchangeability - Product, process or service used in place of another to fulfil the same requirements**

- **Pragmatic Aircraft Stores Compatibility Systems Engineering <u>against agreed Operational Requirements</u>**

- stops self-actualisation & "Activity Traps"
- aircrew & engineers knowing when enough is enough
Required <u>but not sufficient</u>

- **Interchangeability for Joint & Coalition Operations to drive Operational Requirements Vital**

- Primary basis for Analogy as basis of compatibility!
- Required <u>& Sufficient</u>

- **Commonality**

<u>Not</u> Required and <u>not sustainable for coalition</u>

PICS Domains of Warfare – will be used

- **Physical Domain:** The traditional domain of warfare ***where strike, protect and maneuver take place*** across the environments of ground, sea, air and space. Also the easiest to measure effectiveness for lethality and survivability.

- **Information Domain:** The domain where ***information is created, manipulated, and shared***. This domain is where the C2 will occur. The force has the capability to collaborate. Most sensitive of the domains to protect and defend.

- **Cognitive Domain:** The domain of the ***mind of the warfighter and the supporting populous***. Battles and wars are won and lost. This is the domain where tactics, techniques and procedures reside. Explicit treatment of this domain in analytic models of warfare is rare.

- **Social Domain:** The social domain is the domain covering those sets of ***interactions between and among force entities***

Internet Engineering Task Force Approach to drafting & Approving Consensus Documents.... we should use where practicable...

An open, international community of network designers, operators, vendors, and researchers concerned with the evolution, architecture and the smooth operation of the Internet.

The Internet Engineering Steering Group (IESG)

Internet Architecture Board (IAB). The IAB is a technical advisory group of the Internet Society. Its responsibilities include:

Architectural oversight:

Standards process oversight and appeal:

administration of assigned numbers.

External liaison:

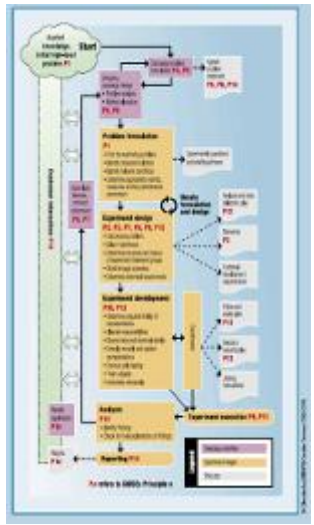
Internet Research Task Force (IRTF)

IRTF Research Groups work on topics related to Internet protocols, applications, architecture and technology.

Publication of Internet Standards — Requests for Comments (RFCs)

Need any differences to protocols for agreeing on proposed and draft documents? ISO???

TTCP GUIDEx – will be used...



- **TTCP – NATO RTO Action Group**
- **Refinement, focus, extrapolation**
- **Internal and External Validity**
  - **Identifying Cause and Effect**
  - **Relating to the Real World**
- **Break-it**
  - **Stressful Scenarios**
  - **Capable and Intelligent Enemy**
- **Communicate**
- **Work being used by NATO RTO M&S Group**
- Robust experimentation methods from the sciences can be adapted and applied to military experimentation and will provide the basis for advancements in military effectiveness in the transformation process.
- 14 Principles & good experimental design practices to counter the '21 threats'.
- Who should read the GUIDEx?

• Those who ask force capability questions and act on the answers.
• Those who decide how the force capability question is to be addressed and what methods are to be used.
• Those who design, execute, and interpret defense warfighting experiments.
• Those engaged in Operational Test & Evaluation (OT&E).
• All those for whom experimentation matters!

Hayes (2007??) says a CoBP /Cookbook not possible

- Do you agree???

US - Standards – post Secretary Perry's Blood - Letting

- **There are the following key standards and specifications that will need to be drawn upon (and perhaps others coming from SP2 Questionnaire)**

- **Materials**

- MIL-STD-810
- MIL-STD-461/2 (MIL-E-1385B)
- MIL-STD-464

- **Process**
  - ISO 9000, 14000, 15288
  - EIA/ANSI STD 632 …
  - MIL-STD/HDBK-1763
  - MIL-STD/HDBK-516
  - MIL-STD/HDBK-1472
  - MIL-STD-881 & 882 – the 3rd most influential US STD
  - NATO ITOPs
- **Product**
  - MIL-A-8591 - the most successful ASC STD ever, and it's a Spec!
  - MIL-STD-1553/1773
  - MIL-STD-1760
  - MIL-STD-3014
  - IEEE for networks
  - Services – architecture/interface?
  - NATO RTO C2 COBP
  - IPV6
  - OSA
  - LISI
  - SOA
  - TTCP GUIDEx
  - Gaussian vs networked power laws…

MIL-HDBK-1763 – framework

will be expanded to all systems and to Mission Level

- The US' second most effective STD, is now a Handbook …
- Aircraft Stores Certification / Compatibility
- 'Standard' view of framework for use of previous work, for Analogy & Similarity
- First real successful systems engineering, integrated:
  - M&S
  - Test 100 Series – Ground Tests
  - Test 200 Series - Flight Tests

MIL-STD-810E

JTEM / JMETC

Core to the US and allies for exercises is use of the JTEM planning model: issues?

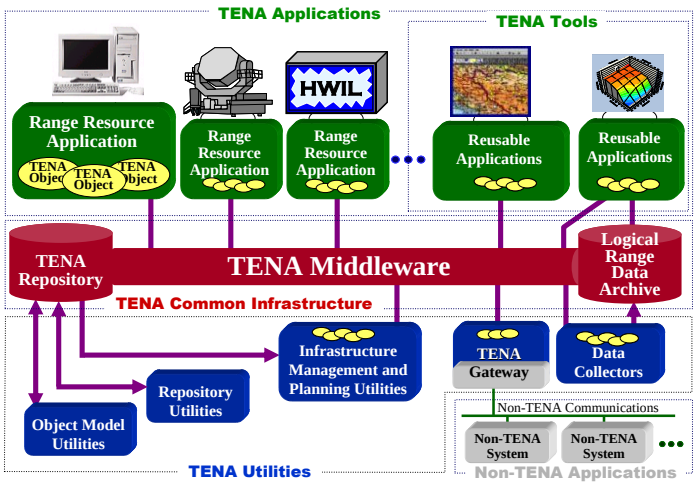
AOP-11 to be used for assessing interoperability and recording results...

L-V-C

- Who should play

HLA / DIS

TENA – will be used



What specific validation strategies are recommended for air armament NEO?

- Agent based distillations
- Closed Loop Models/Simulations
- Seminar wargames
- Hardware in the Loop synthetic environments
- Human in the Loop Wargames
- Human in the Loop synthetic environments
- Field Training or Command Post exercises
- Field trials

Implications....

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-
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TADIL / TCDL / LINK 16 – 605th etc Testing of the networks ....

NexRI

Battlelab / MSTARs / MARs ….

Open System Architectures

Service Orientated Architectures

Mission planning

Mission rehearsal

Safe escape

Safety templates

EBO / Munitions effectiveness

The other systems engineering best practice standards planned to be in day to day use in your organisation?

- REPLACE / Rdata / “Thunking” technologies

ADF Plan for Software Aspects of Certification” addressing AAP 7001.054, AAP 7001.067 and DI(AF) OPS 1-19 aviation risk management criteria.

How do you propose that your proposed methods for NexRI and NEO / TADIL systems for aerospace applications to V&V and/or T&E be best implemented in the ADF?

How do you propose that the ADF implements any of your future recommends as to how the emergent properties of aerospace Human Machine Interfaces be tested?

How do propose that future training & exercises changes be implemented?

What acquisition strategies for such systems are recommended?

What are the Key Performance Indicators for Cost /Performance & Schedule that you would recommend to judge the success of such strategies? MOE & MOPs are needed too. Have you experience with these KPI's or did you just dream them up for this survey?

Are you aware of any Case Studies already conducted in this or related areas?

What are some lessons learned if you are familiar with other implementations?

How should the ASCC, ABCA and Office for Interoperability address higher levels of interoperability.

How should personnel be better educated, if required, on network-enabling and/or tailored-effects operations?

Is a code of best practice that incorporates modelling and simulation into ground and flight T&E and experimentation frameworks for aerospace mission systems achievable now?

Have you been involved with any case studies of the application of this code of best practice for experimentation to real world avionic mission system upgrades and to network enabled operation experimentation.

Coping with Complexity – how do we make this understandable for mere mortals?

Guassian vs power laws…

The key seven attributes consider:

- **Properties:**
  - **Aggregation** – emergence of large scale behaviours from less complex agents
  - **Diversity** – sufficient variety of subsystem actors
  - **Flows** – focus on how the subsystems interact
  - **Non-linearity –** no dependable chain of cause and effects
- **Mechanisms**
  - **Tagging** – ability to mark/identify specific kinds of actors
  - **Building blocks** – pick out loosely the knowable elements, or processes
  - **Internal models** – ability to identify patterns, regularities or influences

Your thoughts?

JAIME Experimentation CoBP

- Aircraft Mission Environment Interchangeability not just compatibility
- 'Standard' view of framework for use of previous work, for Analogy & Similarity
- Covering all Warfare Domains - not just the Physical/Technical + Information/Cognitive/Social
- First real successful systems engineering, integrated:
  - Test 100 Series - Ground Tests
  - Test 200 Series - Flight Tests

What were the strengths and weaknesses of this and the CEDP Approach use by AS and the US.

Comments on Draft Jaime Experimentation Framework/Ontology attached at the end of this document.

Is it worthwhile / useable by you and by your organisation?

- Taking the systems engineering to the next level and cover the ISO 15288 Life cycle model too the framewaork now has :
  - Test 000 Series M&S – to integrate M&S, get better terminology going, provide a Virtual and Constructive framework for the assumed Live entities in the ground and flight test ...
  - Test 100 Series - Ground Tests – DT & OT
  - Test 200 Series - Flight Tests – DT & OT
  - Test 300 Series – In-Service Operations Maintained – R&M done, service weapons firings done in training and in tests, ECPs checking/qualification !

  - ASC had 10 Disciplines -> What are the 10 JAIME & EBO Disciplines what's the latter equivalent needs to be explored ???

- The Framework now assumes that an L-V-C could be put in place of any entity to get interchangeability – eventually, so needs to meet the level of integration... begs a lot of questions – JMETC key. Needs work and input.
- The level of operations builds from subsystem, to system, to joint – it does NOT address bit parts etc... Hence the "Functions" need to cover Vehicle, Sensor, Shooter, C2, the network enabled Test/Training Range, and other roles too presumably such as paradrops and even transports
- Each test needs to be set up for Network-enabled Sensor, Intell/C2 and Shooter (of which the latter is covered as a stand-alone for most of the MIL-HDBK-1763 tests at the moment!) Adding in sensor and C2 could be done in spate tests – but would really ramp up the size of the framework – which will be avoided, if we can.
- The framework must be transparent to sea, sub-surface, land and space...
- The Cognitive Domain is the one that seems thinnest on the ground, is key to the JAIME and not really my own area of speciality – Needs A Lot of Work (NALOW) ->605th / DSTO / JMETC / Dr Amir Morris...
- Colour Codes – background highlight lifecycle left to right and the joint in purple vertically. Text colours are Green – Done, Orange, a plan is present and Red – no plan as yet. Note that all need sensor and C2 view/requirements added in as yet.

Your thought and views on the statement/assertion "Accreditated M&S needs to be via the school of hard knocks and usage – not 'independent' certification/accreditation!"

Maturity/health of OCD/OR/Conops / FPS etc... See also SP1 !

Do you have any other comments that you believe may be relevant to the research project?

Please advise if you're willing to:

- do a personal interview to make sure the research accurately captures all your needs and perspectives on this sub-problem,
- your interest in being involved in the other sub-problems and the Case Study, and
- advise the researcher of any other key individuals who you would recommend should also be participating in this research too – voluntarily or not!

Attachments:

1. JAIME Experimentation CoBP Test Framework/Taxonomy.