A Guide to Best Practice in C2 Assessment

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DERA/CDA/SEA/AIR/WP000061

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August 1999

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A GUIDE TO BEST PRACTICE IN C2 ASSESSMENT

Introduction[1]

The guidance contained in this paper is intended to help analysts and teams get off to a good start in the right direction in C2 analysis studies. It is not intended to be a prescription or to subvert the role of expert technical input which will be specific to each study. Expert analysts will know when it is safe and appropriate to deviate from the guidance (and how to document such deviation), whilst less experienced analysts will find it helpful to follow best practice unless guided away on a particular study by the relevant experts or study design authorities.

NATO has recently adopted a Code of Best Practice (COBP) for Command and Control (C2) Assessment (Ref. 1). This document has been reviewed by a panel of analysts from CDA and the following recommendations formulated:

- Best practice in the UK includes additional elements to those documented by NATO and a UK-specific guide containing key points should be prepared as a specific addendum to Ref. 1;
- The combined COBP should be recommended for use by all Defence analysts in the UK involved in C2 assessment;
- The NATO COBP plus UK addendum should be re-expressed as a shorter, bullet-point guide to facilitate uptake by analysts.

This document is the proposed bullet-point guide and is aimed at the practising Operational Analyst in the UK. It assumes familiarity with Defence issues, and with the general approaches to Operational Analysis (OA). Its aim is to give a quick and easy guide to the key points of best practice in approaching the analysis of command and control (C2) problems.

1 NCOBP chapter 1

It is envisaged that this document will also be used as a checklist by reviewers of study designs. This will help create an auditable trail and should assist in improving quality of analysis (will make studies more successful). This document follows the structure shown in Figure 1.

This guide is intended to assist the community in dealing with, and overcoming, the barriers to effective analysis of C2.

The solid bullets in this document indicate Best Practices that are applicable to all C2 studies, while those marked with hollow bullets identify Best Practices that should be applied when relevant to the particular study scope.

Definition of C2:

The increasing use of information technology in a vast array of military arenas has caused many analysts to emphasise different aspects of Command and Control (C2). For example, the phrase C3I (command, control, communications, and intelligence) and its extension C4ISR (adding computers, surveillance, and reconnaissance) have been widely used. These and other variations simply emphasise different components of the larger C2 processes and systems. The phrase C2 has been used throughout this report as a surrogate for all these different formulations.[2]

Why is C2 Special?

C2 is special because it explicitly involves representation of the human component. In the military context, C2 issues thus arise primarily from the complex interactions of distributed teams of humans operating under stress imposed externally and internally. That focus creates a multi-dimensional, complex analytic space. Combat involves multi-sided dynamics including friendly, adversary and other actors, action-reaction dynamics, and tightly-connected interactions among subjective elements such as organisations, cultures, morale, doctrine, training, and experience and between those subjective elements and the combat arenas. C2 issues are difficult to decompose and recompose without committing errors of logic. Moreover, the composition rules by which the various factors inherent to C2 interact are poorly understood except in arenas that have been previously studied in detail. Finally, the C2 arena is weakly bounded, with issues that, although on initial examination appear quite finite, prove to be linked to very high-level factors. For example, tactical performance may be tied to national culture.

Analyses of C2 are also often constrained by factors that are beyond the boundaries of the research. For example, security policies may restrict data availability and otherwise constrain the analysis. The availability of data often limits the scope of an analysis. Moreover, the time and resources available to conduct an analysis are often severely constrained because the decision processes being supported are being driven by outside planning, operational, or budget decision processes.

Finally, because of the complexity of C2 processes and systems, analysis in this area requires the ability to understand how dimensional parameters (DP), measures of performance (MoP), measures of effectiveness (MoE), and measures of force effectiveness (MoFE) interact. The cumulative set of these measures is denoted as measures of merit (MoM) in the guide. Determining the (precise) nature of these relationships nearly always proves to be an analytic challenge.

Taken together all these factors mean that C2 modelling and analysis is more uncertain and therefore more prone to risk than the weapon and platform analyses. Indeed, C2 issues have long been regarded as difficult to analyse, and many OA studies have simply assumed perfect C2 in order to focus on other variables.

2 NCOBP section.1.1

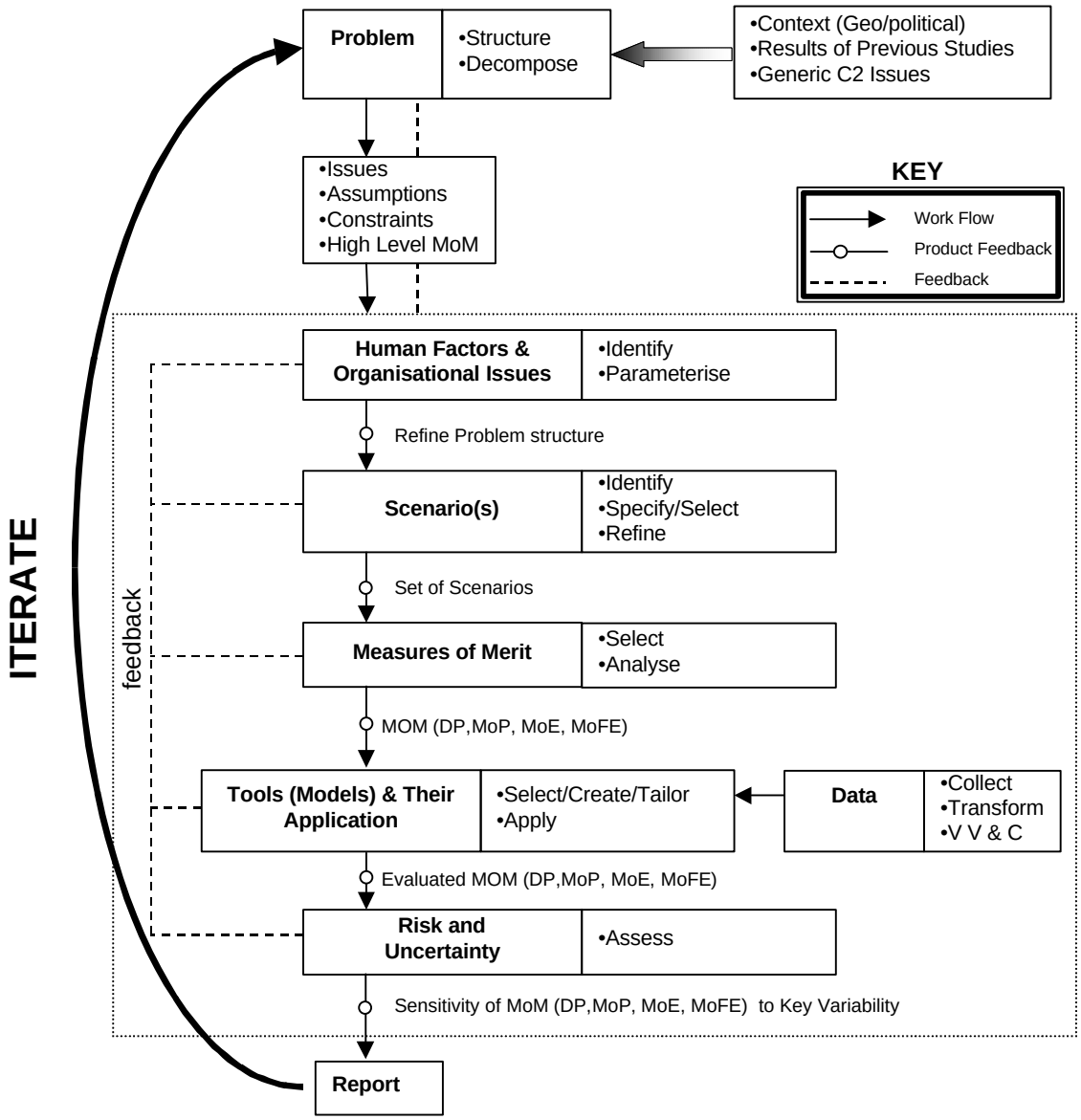

Figure 1The NATO Recommended Assessment Methodology

Global Points of Best Practice

The aim of this guide is to make studies more cost effective, irrespective of their size and scope.

- There is a strong link between C2 and Doctrine, Tactics, Techniques and Procedures and it is important that this is kept in mind during any C2 analysis.
- Documentation must be carried out at all stages of analysis from problem formulation through to study closure. [UK addendum]
- The study must be explicit in its use of language, e.g. the study must define its taxonomy.
- At least two iterations through the assessment methodology are recommended. The first should be used to scope the problem and may use more approximate methods.
- Validation is always necessary. [UK addendum]

The remainder of this guide is structured into sections following the steps illustrated in Figure 1.

Problem Structuring[3]

Effective problem structuring is fundamental to the success of all analysis, but particularly in C2 assessment because the problems are often 'messy' - involving many dimensions and a rich context. Problem structuring involves decomposition of the analytic problem into appropriate dimensions such as structures, functions, mission areas, command levels, and C2 systems. The outputs of problem structuring are a clear articulation of the issues, the key assumptions, the intended scope and constraints under consideration, and the development of high level measures of merit (MoM)

- Explicit problem structuring must precede construction of concepts for analysis or method selection. This is not a trivial exercise but proper resourcing up front will improve overall efficiency.
- A careful review of previous work must be carried out as a valuable source of ideas, information and insight; as well as identifying pitfalls and analytic challenges.
- Problem structuring must address the geo-political context of the problem and seek to identify the "generic" C2 issues contained within the terms of reference for the study.
- Problem structuring must not only provide problem segments amenable to analysis, but also a clear and valid mechanism for meaningful synthesis to provide coherent knowledge about the original, larger problem.
- A clear understanding of the decisions to be supported by the analysis and the viewpoints of the various stakeholders (customers, users, suppliers, etc) is essential to elucidating the study issues.
- Problem structuring must be broad and iterative in nature, accepting the minimum of a priori constraints and using methods to encourage creativity and lateral thinking. [UK addendum]

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3 NCOBP section 1.8

- Mapping techniques (especially cognitive and causal mapping) are the best way to express the various relationships within the problem space and to identify 'chains' of analysis. [UK addendum]

- A structured analysis of potential benefits[4] must be carried out (ideally using causal mapping) as a basis for constructing appropriate Measures of Merit (MoM). [UK addendum]

- Derivation of high level MoM must start with ideal measures of the desired benefits before considering what can be practically generated by analysis (the latter may force the use of surrogate MoM, but these must be clearly related to the desired measures). [UK addendum]

- Risk analysis techniques should be used to complement the benefits analysis (see section [Risk]). [UK addendum]

- C2 assessment often involves impacts on Defence business, outside the context of a particular campaign and operations, and MoM hierarchies must capture this. [UK addendum]

Human Factors and Organisational Issues[5]

Human Factors and Organisational issues can be difficult to analyse. However such issues are central to structuring problems and therefore it is important to decide early on how to represent them. Figure 2 shows the way in which human factors and organisational issues can be viewed. Studies must be aware where these issues affect the system under analysis.

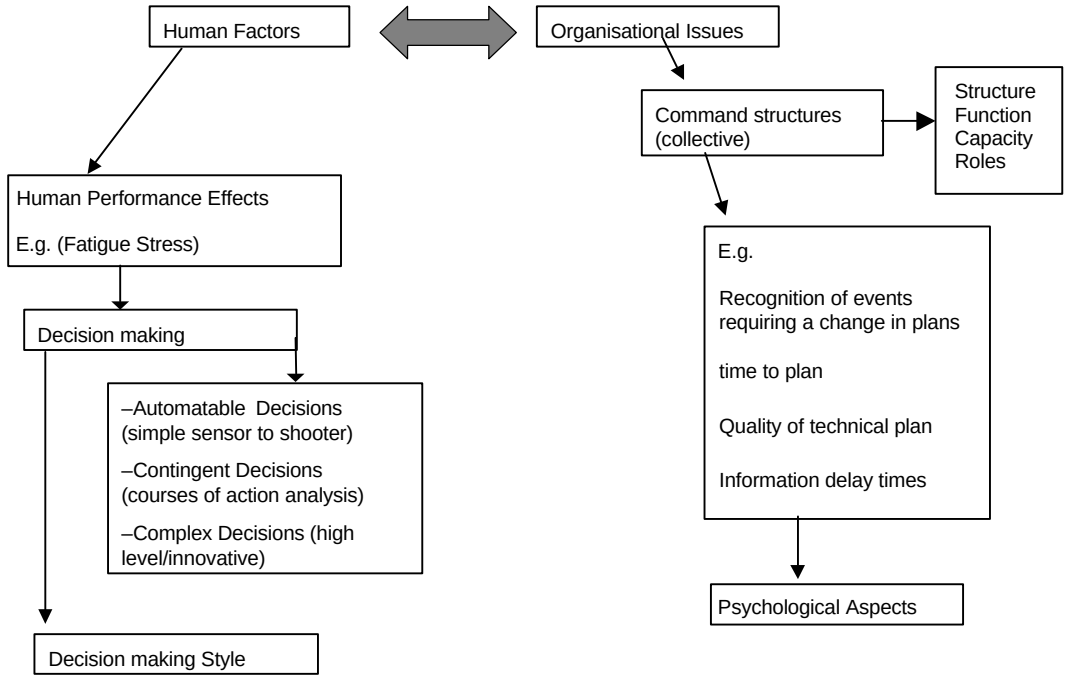

Figure 2 Areas of Impact for Human Factors and Organisational Issues.

- C2 analysis must consider the relevance of these human factors and organisational issues and this must be reviewed early in the analysis. Explicit documentation of any exclusions must be made.

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4 The structured analysis of benefits is a logical process which seeks causally to map changes in system dimensional parameters or MoP onto potential benefits which can be valued directly by decision-makers.
5 NCOBP chapter 2

- Organisational issues should be decomposed into constituent elements for analysis, and hypotheses developed about the effect of these elements. However it should be recognised that the whole may be more than the sum of the elements.

- Experts in the area of human factors and organisational issues must be consulted and involved within C2 assessment teams.

- Human performance issues (such as Fatigue and Stress) should be incorporated as parameters in models used to analyse issues that require human activity.

- The analyst must determine which of the three decision-making modes are involved (automatable, contingent, complex).

- Decision making that is automatable, contingent, rule or algorithmically based can be modelled directly, but error representation must be incorporated if humans are involved in the actual process.

- Complex decisions are best modelled with 'human in the loop' tools and techniques[6], but new closed form modelling techniques are being developed.

- The analyst must separate human operator performance issues from higher cognitive issues.

- Use hypothesis-testing logic to review organisational issues, with explicit consideration of structural, functional and capability areas.

- The use of integrated analysis tools that focus on key variables that drive human factors and organisational issues will often prove useful in simplifying their analysis.

- Sensitivity analysis must be carried out when dealing with human factors and organisational issues.

Scenarios[7]

Definition:

SCENARIO: A description of the area, the environment, means, objectives and events related to a conflict or a crisis during a specified time frame suited for satisfactory study objectives and the problem analysis directives.[8]

SCENARIO [UK addendum]: The above definition can hold for any level (tactical, operational, strategic). At the lower levels these are called vignettes or sample situations and may be bounded in time, geography, function or a combination of these.

- Scenarios must relate back to Defence Policy and the audit trail must be documented.

- Analysts must use approved scenarios.[9]

- Multiple scenarios will be required.[10]

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6 War gaming, synthetic environments etc
7 NCOBP chapter 3
8 NCOBP section 3.1.2
9 UK: Use a SAG scenario or an endorsed developed/generated scenario.

- Scenarios should be selected for the problem space.

  a) Identify range

  b) Specify key factors

  c) Refine selection to focus on key segments of scenario space.

- The scenario set must be complete and fully test all of the C2 issues.

- Scenarios must be subjected to military review and this review documented. [UK addendum]

- Scenario based analysis may need to be supported/supplemented by military/analytical judgement in order to span the whole problem space.

- The analyst must identify what/whom the C2 is supporting.[11]

- The analyst must investigate and document the impact of all parameters shown in Figure 3. Identify which parameters vary and which remain constant.

- The impact of C2 on doctrine and tactics must be documented.

- Scenario must include[12]; C2 process, organisation, infrastructure, and Human Factors.

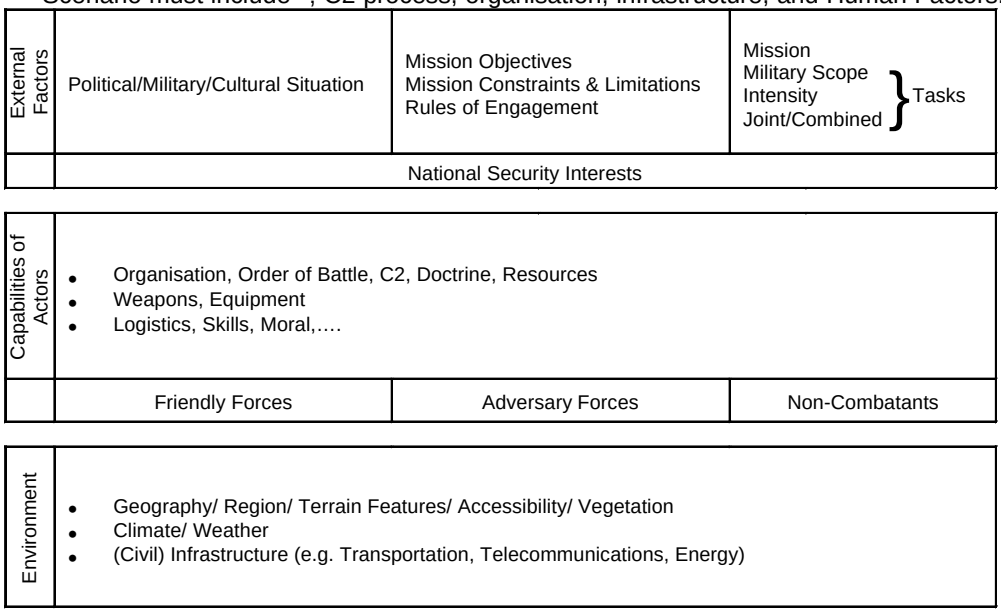

Figure 3 Scenario Framework[13]

10 Ideally OA will be scenario independent. Scenarios are used to investigate possible futures in a robust manner and should be selected with this in mind.
11 As C2 spans the command hierarchy and impacts across the mission space it is vital to identify the 'enterprise' which the system is trying to support in order to identify/select the scenario/vignette and models which are relevant.
12 Studies will need to generate this information for most SAG scenarios.
13 NCOBP figure 3.1

Measures of Merit[14]

Definition:

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 Effectiveness (MoE) which focus on the impact of C2 within the operational context.

Measures of Performance (MoP) which focus on internal system structure, characteristics and behaviour.

Dimensional Parameters (DP) which are the properties or characteristics of the inherent physical system.

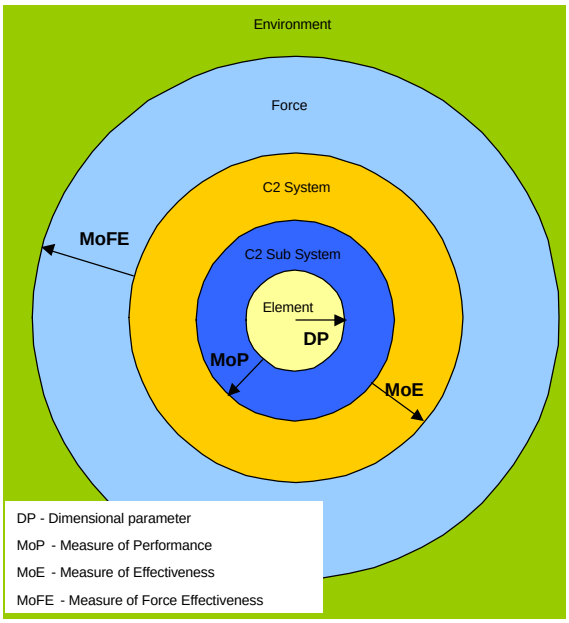

Figure 4 Relationships between Measures of Merit.[15]

MOM	FOCUS	SCENARIO	EFFORT REQUIRED	NUMBER	VALUE	COMPREHENSION	GENERALISABILITY
MoFE	Outcome	Dependent	High	Few	High	Military	Low
MoE	C2						
MoP	Systems						
DP	Process	Independent	Low	Many	Limited	Technical	High

Table 1 Characteristics of Measures or Merits[16]

14 NCOBP chapter 4
15 NCOBP figure 1.4
16 NCOBP table 4.1

- The principal objective of the use of MOMs is to determine the degree to which C2 investments may improve force/defence business effectiveness.
- No single measure or methodology exists that satisfactorily assesses the overall effectiveness of C2.[17]
- The analyst must determine the levels of hierarchy appropriate for the level of analysis to establish the appropriate MOM. The analyst must also identify the quality of evidence required for decision support.
- MOMs must be discussed and agreed with the decision-makers during problem formulation. [UK addendum]
- The analyst must identify MOMs which are practically obtainable.
- The analyst must specify the means of collection of MOMs.
- The analyst must assure the validity and reliability of MOMs. Table 2 & Table 3 give guidance on MOM criteria. Traditional MoFE and MoE are not always applicable in Operations Other Than War (OOTW) and other MOM may have to be developed.[18]
- MOEs can be categorised into time-based and accuracy-based measures.[19]
- There is often a trade off when dealing with time-based[20] and accuracy[21] measures. This implies a trade off between speed of performance and accuracy of performance.[22]

VALIDITY CRITERIA	DEFINITION
Is it Mission Oriented?	Relates to force/system mission.
Is it Realistic?	Relates realistically to the C2 system and associated uncertainties.
Is it Appropriate?	Relates to acceptable standards and analysis objectives.
Is it Inclusive?	Reflects those standards required by the analysis objectives.
Is it Simple?	Easily understood by users.[23]
Is it Causal?	Causal relationships between variables can be identified.
Is it Targeted?	Target object and only the target object is measured.
Can it be Generalised?	Degree to which measures can be extended to other populations/environments.
Is it sensitive?	Statistically sensitive in support of hypothesis testing.

Table 2 Validity Criteria of Measures[24]

17 NCOBP section 4.7
18 NCOBP section 4.5.2
19 NCOBP section 4.3.1
20 NCOBP section 4.3.11 examples of time based metrics
21 NCOBP section 4.3.1.2 examples of accuracy base metrics
22 Examples of MOMs are provided in NCOBP annex VII
23 Can be complex.
24 NCOBP table 4.2 with additions from section 4.2.3.1

RELIABILITY CRITERIA	DEFINITION
Is it Discriminatory?	Identifies real differences between alternatives.
Is it Measurable?	Able to be computed or estimated.
Is it Quantitative?	Can be assigned numbers or ranks.
Is it Objective?	Defined or derived, independent of subjective opinion.
Is it Sensitive?	Reflects changes in system variables.
Is it Consistent?	On repetition the same results are obtained.[25]

Table 3 Reliability Criteria of Measures[26]

Tools (Models) and their Application[27]

Definition

For the purpose of this guide, the definition of tools is broad but has a focus on models. It includes all tools (models, simulations, or other quantitative or qualitative techniques), whether used for analysis, training, or operational purposes, which can be used to examine and evaluate C2 issues. It includes live, virtual, constructive, stochastic and deterministic modelling approaches. The **primary focus** of this chapter of the guide is clearly on **constructive modelling** and how best to enhance and apply this to the analysis of C2 impacts on battle outcome. The logic and arguments, however, apply across the range of C2 analyses. Similarly, the term "modelling" here includes both modelling and simulation.[28]

- All analysis of C2 demands a high level of creative problem structuring.
- Experimental design must be considered as the basis of analysis plans.[29]
- The key to the problem of C2 analysis is in making the quantified link between C2 MoP and C2 MoE and the resultant impact on MoFE.
- A mix of tools is often the best choice.[30]

25 Must remain aware that variation in measurements (e.g. due to human factors) may cause an unacceptable level of inconsistently.
26 NCOBP table 4.3
27 NCOBP chapter 5
28 NCOBP section 5.1.2
29 NCOBP section 1.13
30 NCOBP section 1.12

- Issues in Model Selection: The following must be thought about when considering model selection.

  The representation of different types of human behaviour: automatable, cognitive, complex.

  Homogeneous models vs. hierarchies/federations.

  Stochastic vs. deterministic models

  Adversarial representation

  Verification, Validation and Accreditation[31]

  Conduct of sensitivity analysis.

  Models must be agile and fast running.[32]

  Models must be capable of representing a wide range of scenarios.

  Models' representation of C2 must be 'Good Enough' i.e. fit for purpose.

- Fast models can be used during problem formulation to scan the problem space. This allows identification of areas of interest and the complexity of the problem to be investigated. This can then be used to drive the model selection to those which analyse the problem in greater depth.

- The following are guidelines for model selection and development.

  [UK Addendum: The below should apply at an appropriate level of aggregation]

  Models must represent information as a commodity[33]

  Models must represent the realistic flow of information around the battlespace (operation space)

  Models must represent the collection of information from multiple sources and the tasking of information collection assets

  Models must represent the processing of information

  Models must represent C2 systems as entities on the battlespace/operational space.

  Models must represent unit perceptions built, updated, and validated from the information available to the unit through its information systems

  Models must represent the commander's decision based on the unit's perception of the battlespace/operational space.[34]

  Models must represent information operations.

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31 In the UK there is no formal Accreditation, but validation must be reviewed in the context of each study.
32 There is a drive to shorter study times and of broader coverage to reflect greater future uncertainties and also in the context of SMART procurement.
33 This statement and the following seven have been modified from those given in the NCOBP section 1.12
34 This allows the representation of deception, shock and surprise due to the variation in perceptions.

Table 4 gives some indication of the time scales and tradeoffs for different modelling techniques and developments.

Technique	Typical Application	Systems	People	Ops/ Mission	Resources	Lead Time		Credibility
						Create	Use	
Analysis	Closed form; Statistical	Analytical	Assumed or Simulated	Simulated	Relatively Modest	Weeks to months	Weeks to months	Fair to Moderate
Constructive	Force on Force Models; Communication systems	Simulated	Assumed or Simulated	Simulated	Moderate	Months to Years	Weeks to months	Moderate
Virtual	Human in the Loop	Simulated	Real	Simulated	High	Years	Months	Moderate to High
Live	CPX[35] FTX	Real	Real	Real	Very High	Years	Weeks to months	High
Actual Ops	After action reports; Lessons Learned	Real	Real	Real	Extremely High	N/A	N/A	Very High

Table 4 Assessment techniques[36]

Data

This section is primarily concerned with those issues that particularly impact on C2 studies.General data issues are not covered, as there are various initiatives in existence on data management.

- Due to Human Factors effects, data on human performance needs to be generated by experiment. The analyst must be aware of the validation issues that this raises.
- Collection of human performance data is time consuming and expensive and therefore must be budgeted for. [UK addendum]
- A broad base of skills is required for C2 analysis. This may range from psychological skills through to system technical skills.
- Analysts must be careful to capture and document the assumptions (explicit and implicit) brought by the participants to any Human in the Loop experiment. [UK addendum]
- All data and assumptions from any study must be documented. [UK addendum]

35 CPX - Command Post Exercise. FTX - Field Training Exercise.
36 NCOBP table 1.1

Risks[37]

The adoption of the guidance contained in the Guide to Best Practice should help minimise the risks involved in C2 studies. The following risks and uncertainty issues remain and are intrinsic to any C2 study.

- An explicit risk analysis is best practice. [UK addendum]
- As in all OA, the primary approach to assess risk and uncertainty is sensitivity analysis. The goal of the sensitivity analysis should be to establish the regions for which the results are valid and to isolate those factors that may introduce uncertainty.
- In C2 assessments, analysts need to be particularly alert to the possibility of chaotic behaviours arising from dynamic interactions, because human and organisational factors are particularly prone to this type of instability.
- The need for and results of sensitivity analyses must be stressed in discussions with the decision makers. This is to avoid under-resourcing of this critical activity.
- The analyst must be aware of the assumptions and limitations included in models, scenarios, and data structures.
- Humans always bring assumptions with them to experiments and these need to be identified and? collected to form an auditable trail.
- When dealing with human factors the analyst must be aware of the choice of courses of action that are possible. The analyst must ensure that these courses of action are represented and not allow discontinuous, non-linear divergence to confuse the study.
- There is a risk in defining the boundary of the problem space (as C2 problems are weakly bounded) and this may cause either the exclusion of the area of interest or the swamping of the study by the analysis of unnecessary effects.
- In Human in the Loop experiments there is a danger of bias in subjective judgements.[38]

References

1. NATO Code of Best Practice for C2 Assessment, AC/243(panel7)TR/8 1998 Edition NATO U/C. (Available online at http://www.dodccrp.org)

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37 NCOBP section 1.14

38 These type of experiments are typically unrepeatable due to resource constraints.

Background to Code of Best Practice

This document is based upon the NATO Code of Best Practice for C2 Assessment (NCOBP) produced by the Studies, Analysis and Simulation panel (SAS). The Ad Hoc Working Group on the Impact of C3I on the Battlefield was formed by Panel 7 of the NATO Defence Research Group in 1991 to assess the state of the art in C2 analysis. Based on the recommendations of the Ad Hoc Working Group, Panel 7 constituted Research Study Group-19 (RSG-19) to address issues of methodology, measures of merit, and tools and analysis. The panel also addressed issues of improving a nation's capability to examine C2 acquisition and decision making.

At the October 1995 RSG-19 planning meeting, the group determined that the primary product of RSG-19 was to be a Code of Best Practice for assessing C2. As part of selected RSG-19 meetings, workshops would be conducted to support the development of the major sections of the COBP. Workshops were conducted on Measures of Merit (Canada), Scenario Development (Netherlands), C2 Systems, Structures, Organisations, and Staff Performance Evaluations (Norway), and Models Used for C2 Systems and Analysis (US/UK). Representatives from the nations in parentheses took the lead in organising the workshops and summarising the results. Towards the end of the period, Panel 7 was superceded by the SAS Panel under the new NATO Research and Technology Organisation (RTO).

A review of the NATO COBP by CDA analysts took place at a workshop held in October 1998 at which it was determined that the COBP, with the addition of UK specific addenda, should be recommended for adoption by the UK OA community. It was also recommended that this shorter, bullet-point guide should be produced to facilitate uptake of the COBP.

Glossary

Approved Scenario - A scenario adopted by the political and military community.

Automatable Decisions - Or 'simple decisions', for which the range of options is finite and known and the criteria for selecting among them are clear.

C2 - Command and Control

C3I - Command, Control, Communications, Intelligence

C4ISR - Command, Control, Communications, Computers, Intelligence, Surveillance, Reconnaissance

CCIS - Command, Control and Information System

COBP - Code of Best Practice

Complex Decisions - Require the decision making system to not only recognise when a decision needs to be made, but also (a) identify the relevant set of options, (b) specify the criteria by which they will be judged, and (c) determine when the decision would be made.

Contingent Decisions - Those decisions for which a set of alternative actions have been pre-determined and are appropriate to the situation, but battlespace developments and new information will be needed to resolve which is the proper course of action.

CPX - Command Post Exercise

DP - Dimensional Parameter; the properties or characteristics inherent in the physical C2 systems. Examples include bandwidth of communications linkages, component size, number and variety of wavebands and luminosity of display screens in command centres.

DRG - Defence Research Group (NATO)

FTX - Field Training Exercise

HIL - Human in the Loop

Metrics - Standards of measurement, in this case those in C2 systems.

MoE - Measures of Effectiveness (C2); focus is on the impact of C2 systems within the operational context. Examples include the ability to formulate plans that work to achieve objectives, the capacity to create a common operating picture of the battlespace, reaction time and susceptibility to jamming.

MoFE - Measures of Force Effectiveness; focus is on how a force performs its mission or the degree to which it meets its objectives. Examples include territory gained or lost, rate of advance, combat loss ratios, and casualty ratios.

MoM - Measures of Merit; used to evaluate both the overall effectiveness of command and control and the performance of C2 systems. For the purposes of the COBP these include MOFE, MoE, MoP, and DP.

MoP - Measures of Performance; the focus is on internal system structure, characteristics and behaviour. Examples include error rates, database update speed for C2 functions, signal to noise ratios, and accuracy of information transmitted.

MORS - Military Operations Research Society

OA - Operational Analysis

OOTW - Operations Other Than War

Operation Space - The battle space is a subset of this, it also includes OOTW and military operations during peace time. E.g. provision of logistics in barracks.

OR - Operations Research

RSG - Research Study Group

SAS - Studies Analysis and Simulation

Scenario - A description of the area, the environment, means, objectives and events related to a conflict or a crisis during a specified time frame suited for satisfactory study objectives and the problem analysis directives.

Sensitivity Analysis - This is the primary tool for assessing risk and uncertainty in OR. It establishes the regions of stability for which the results are valid and isolates those factors that may be introducing uncertainty.

Taxonomy - Definition of terms used

V V&A - Verification, Validation, and Accreditation

V V&C - Verification, Validation and Certification