NATO

COBP

Code Of Best Practice for C^2 Assessment

Revised 2002

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A DoD CCRP/NATO Collaboration

This major revision to the Code of Best Practice for C2 Assessment is the product of a NATO Research and Technology Organisation (RTO) sponsored Research Group (SAS-026). It represents over a decade of work by many of the best analysts from the NATO countries. A symposium (SAS-039) was hosted by the NATO Consultation Command Control Agency (NC3A) and provided the venue for a rigorous peer review of this code.

This publication is the latest in a series produced by the Command and Control Research Program (CCRP) under the auspices of the Assistant Secretary of Defense (C3I). The CCRP has demonstrated the importance of having a research program focused on the national security implications of the Information Age. The research sponsored and encouraged by the CCRP contributes to the development of the theoretical foundations necessary to support the Information Age transformation of the Department. Other CCRP initiatives are designed to acquaint military and civilian leaders with emerging issues related to transformation. This CCRP Publication Series is a key element of this effort.

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CHAPTER 1

Introduction

> *So the principles which are set forth in this treatise will, when taken up by thoughtful minds, lead to many another more remarkable result; and it is to be believed that it will be so on account of the nobility of the subject, which is superior to any other in nature.*
>
> —Galileo Galilei (1638)

Command and Control Assessment Challenges

NATO and its member nations are in the midst of a revolution in military affairs. There are three major dimensions to this revolution—a geopolitical dimension, a technological dimension, and a closely coupled conceptual dimension. This multidimensional revolution poses significant new challenges for analysis in general and for command and control assessment in particular.

The changed *geopolitical* context is characterised by a shift from a preoccupation with a war involving NATO and the Warsaw Pact to a concern for a broad range of smaller military conflicts and Operations Other Than

War (OOTW). Analysts will increasingly be called upon to provide insights into these non-traditional operations.

Advances in *technology*, particularly information-related technologies, offer military organisations unprecedented opportunities to significantly reduce the fog and friction traditionally associated with conflict. At the same time, they may prove to be challenges in themselves across a wide variety of realms—technical, organisational, and cultural.

To the extent that they can be achieved, significantly reduced levels of fog and friction offer an opportunity for the military to develop new concepts of operations, new organisational forms, and new approaches to Command and Control (C2), as well as to the processes that support it. Analysts will be increasingly called upon to work in this new *conceptual* dimension in order to examine the impact of new information-related capabilities coupled with new ways of organising and operating.

Definition of Command and Control

C2 has been defined by NATO as Military Function 01: "The Organisation, Process, Procedures and Systems necessary to allow timely political and military decisionmaking and to enable military commanders to direct and control military forces." (NATO 1996) C2 systems are further defined in NATO documents to include: headquarters facilities, communications, information systems, and sensors & warning installations. (NATO 1998).

Other terms are used in NATO member nations that are synonymous with, or closely related to, C2. These include Command, Control, and Communications or Consultation (C3), and Computers (C4), and Intelligence ([C3I] or [C4I]), and Surveillance and Reconnaissance (C4ISR). The term CIS is sometimes used to refer to command information systems. More recently the term "C2" has referred to the collaborative and consultative processes that are an inherent part of coalition operations.

For the purposes of this Code of Best Practice (COBP), the term C2 is intended to be an umbrella term that encompasses the concepts, issues, organisations, activities, processes, and systems associated with the NATO definition of C2 as well as the other terms enumerated above.

Uniqueness of C2 Analyses and Issues

The focus of military research and analysis has predominantly been on the physical domain. C2 issues differ in fundamental ways from physics dominated problems. C2 deals with distributed teams of humans operating under stress and in a variety of other operating conditions. C2 problems are thus dominated by their information, behavioural, and cognitive aspects that have been less well researched and understood. This focus creates a multidimensional, complex analytic space.

Military operations involve multi-sided dynamics encompassing friendly, adversary, and other actors including:

- Action-reaction dynamics;

- Tightly connected interaction among subjective elements such as cultures, morale, doctrine, training, and experience and between those subjective elements and the combat arena;
- Non Governmental Organisations (NGO);
- Private Volunteer Organisations (PVO);
- International organisations;
- International corporations; and
- Transnational, subnational, criminal, and terrorist organisations.

C2 issues are difficult to decompose and recompose without committing errors of logic. Moreover, the composition rules, by which the various factors that impact C2 interact, are poorly understood except in arenas that have been previously studied in detail. Finally, the C2 arena is weakly bounded by issues that on initial examination appear quite finite, but 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 and decision processes. This should be seen as a challenge rather than a problem. Uncertainty and risk associated with a lack of appropriate data need to be embraced as part of the analytical approach. It is unreasonable to expect that data would be available for the performance of future systems and processes that do not yet exist. An experimental component and a modelling and simulation component need to be integrated into modern C2 analyses in order to close the gap in knowledge and data.

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 C2 Effectiveness (MoCE), Measures of Force Effectiveness (MoFE), and Measures of Policy Effectiveness (MoPE) are linked and impact on one another. The cumulative set of these measures is denoted as Measures of Merit (MoM) in the COBP. 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 are more uncertain and therefore more prone to risk than their equivalents in conventional weapon and platform analyses. Indeed, C2 issues have long been regarded as difficult to analyse. Many operational analysis (OA) studies have simply assumed perfect C2 in order to focus on other variables. As a result of these characteristics of C2 analysis, these endeavours will require a heavy element of research within each analysis. This COBP is intended to assist the community in dealing with, and overcoming, the barriers to effective analysis of C2.

Differences Across the Mission Spectrum

There are significant differences among the different parts of the mission spectrum (e.g., MoM) that the assessment team needs to take into consideration. Table 1.1 highlights the differences between traditional combat and OOTW.

Factor	*Symmetric, Conventional*	*OOTW*
Mission/Operation		
Stability	Relatively stable	May be more dynamic
Focus	Enemy	No traditional opponent
Commitment	Common (military)	Uncertain (political/military)
Principles		
Unity	Of command	Of purpose
Decisionmaking	Hierarchical	Consensus
Operations	Surprise, secrecy	Transparency
Information		
Nature of the problem	Known unknowns	Unknown unknowns
Key question	How to get information	What information to get
Focus	Enemy military	Military/political/economic/ social factors
Situation awareness	Common air-land-sea	Limited dissemination, more complex
Databases	Very large, well structured	Larger, less structured
Analysis		
Unit	Battalion level entity	More behavioural
Ease in integration	Relatively easy	Very difficult
Focus	Military (systems, organisations)	Political/Military and societal
Approach	Traditional operation analysis	"Softer" analysis

Table 1.1. Comparison of Symmetric, Conventional Warfare and OOTW Missions & Principles Mission

In symmetric conventional warfare, the mission tends to be relatively stable, there is a clear focus on the enemy, and the military has a common understanding and commitment.[1] Conversely, in OOTW the mission is often more dynamic. This is captured by the often pejorative term "mission creep." In many of the operations in question there is no "enemy." This is obviously true for operations such as humanitarian assistance and disaster relief. In addition, peacekeeping activities involve protagonists who must be treated even-handedly if the operation is to be successful. In the latter missions, political-military ambiguities frequently result in uncertain understanding of the goals and objectives of the mission and a limited commitment.[2] (Starr, Haut & Hughes, 1997)

Principles

Military theorists have frequently propounded basic principles of conventional warfare. Three often cited principles include the need for unity of command, the importance of hierarchical decisionmaking, and the criticality of achieving surprise in operations. A recent book has proposed alternative principles for OOTW. (Alberts & Hayes, 1995) It cites the need for unity of purpose, consensus decisionmaking, and transparency of operations.

Information

In conventional warfare, the issue of information gathering and management focuses on the issue of "known unknowns" (e.g. Where are the enemy's battalions?). For that case, the key question is how to get the needed information (e.g. What are the key signatures for the targets in question? What sensors should we task to exploit those signatures?). Clearly, the focus is on the enemy military and one objective is to assemble a complete, timely, and accurate common picture of the air-land-sea situation. The result is a very large, time-sensitive database, but one that is relatively well structured (e.g. enemy order of battle). Conversely, in OOTW, the problem of information gathering and management is dominated by "unknown unknowns." Thus, the primary question to address is what information to get. The information focus is much more diffuse because of the myriad of military, political, economic, and social factors that must be considered. Consequently, situation awareness is much more complex. Political considerations often make it prudent to limit the dissemination of information, creating a tension between the desire to create shared awareness by increasing information sharing and the need, for political and/or security reasons, to limit information sharing. The resulting databases are frequently larger and less structured.

Analysis

Over many years, the military operations research community has become relatively adept at analysing key aspects of symmetric conventional warfare. As an illustration, analyses of ground warfare often focus on battalion-level operations and techniques have emerged to integrate across those results to derive insights into campaign outcomes. The focus is on military systems and organisations, and the techniques in question involve a broad set of methods (e.g., mathematical programming, decision theoretic approaches) and tools (e.g., models and simulations). Analyses of C2 issues remain among the most challenging, even in warfare contexts. In addition, analyses of OOTW often require consideration of individual behaviour. It has proven very difficult to integrate across these results to derive a comprehensive understanding of the problem. The issue is compounded by the many factors that have to be considered in the analysis process (e.g. military, political, economic, social). This has led to the application of “softer” analytic approaches (e.g., extensive reliance on expert elicitation). Moreover, the very nature of warfare appears to be changing. For example, asymmetric threats are becoming more common, information technologies are impacting C2 processes, and organic structure and dynamics are changing rapidly and in ways we do not fully understand.

Types of C2 Assessments

The assessment team could be called upon to support a wide variety of sponsors (e.g. acquirers of C2 systems, long range planners and programmers, developers of requirements, operational commanders, and trainers). These sponsors will bring different problems to the assessment team (e.g. assessment of alternative systems or concepts, identification and selection of alternative courses of action in an operational context). Some of these will deal with a specific mission (e.g. air defence) while others will need to deal with the entire mission spectrum from forward presence to high intensity conventional war.

Specific problems that the team may be called upon to address:

Requirements Analysis

- Derivation of specific C2 requirements from broad statements of objectives; and
- The establishment of a minimum, standard, or expected level of performance.

Assessment of Alternatives

- Comparison and selection of alternative systems that may be very dissimilar but are designed to achieve a similar purpose;
- Assessment of the utilisation of a system in a new or unexpected application domain or mission;
- Trade-offs between C2 systems and combat systems;
- Analysis of the impact of an organisational change;
- Determination of the most cost-effective approach to achieving the desired objective; and
- Comparison of a replacement system or components of a system.

Research Issues

- Effectiveness of human decisionmaking as a function of system performance or other factors;
- Effectiveness of C2 training; and
- Impact of collaboration on C2 quality.

Support to Operations

- Course of action analysis;
- Real time assessment of mission effectiveness; and
- Rehearsal assessment.

Purpose and Scope of the COBP

This COBP offers broad guidance on the assessment of C2 for the purposes of supporting a wide variety of decisionmakers and the conduct of C2 research described above. It should be noted that this COBP is focused upon the assessment challenges associated with the nature of C2 and does not attempt to specifically address the unique properties and constraints associated with each of the many C2-related problem domains.

Given the increasing interdependence among the elements of a mission capability package[3] (organisation; doctrine; C2 concepts, processes, systems; materiel; education; training; and forces), C2-related analysis cannot easily be done in isolation from a more comprehensive mission analysis. This COBP is meant to support analyses that go beyond the traditional boundaries of C2 analyses.

This new version of the COBP for C2 assessment was developed by SAS-026 building upon the initial version of the COBP produced by SAS-002. This new COBP is a synthesis of decades of expertise from various countries and hundreds of analyses. The COBP was developed using a set of case studies to test out the varied advice and guidance received, and incorporates feedback from users of the initial version. Lastly, SAS-039 provided a peer review of the final draft product.

The earlier version focused on the analysis of ground forces at a tactical echelon in mid to high intensity conflicts. Consequently, the initial version of the COBP did not completely address the full range of important issues related to C2. In developing this new version of the COBP, SAS-026 explicitly focused upon OOTW, the impact of significantly improved information related capabilities, and their implications for military organisations and operations. In addition, SAS-026 was cognisant of the fact that NATO operations are likely to include coalitions of the willing, which might involve Partnership for Peace (PfP) nations, others partners outside of NATO, international organisations, and NGOs. NATO operations may also be “out of area.”

Feedback from users of the original COBP also identified a number of ways in which the original COBP could be improved. These areas were addressed during the development of this version of the COBP.

Cost analyses continue to be explicitly excluded for two reasons. First, cost analysis is a mature discipline that experienced operational analysts already practice. Hence, C2 issues are not unique in the arena. Second, most nations have already developed approaches to cost analysis and cost effectiveness that are consistent with their national approaches to accounting. Because these national practices differ among NATO members, no single approach would be appropriate.

As this COBP is being drafted, novel experiments with new information-related capabilities, particularly networking and ways to accomplish their assigned tasks abound. Advances in technology are expected to continue at an increasing rate and spur both sustaining and disruptive innovation in military organisations. It is to be expected that this COBP will need to be periodically revisited in light of these developments.

Overview of COBP Assessment Philosophy

The COBP assumes that the objective of a C2 system is to exercise control over its environment, through either adaptive or reactive control mechanisms, or some combination of those two approaches. This provides the context and point of departure for the assessment of C2.

Analysis of C2 should consider all the relevant actors, military command levels, and functions involved and should investigate issues of integration across disparate organisations, military command levels, and functional domains over time. Consideration should also be given to the robustness and security of information systems and to human computer interface issues. Human behavioural, physiological, and cognitive factors, along with organisational and doctrinal issues, must be considered in C2 analyses.

C2 assessments must also consider a range of missions, adversary capabilities, and adversary behaviours. Moreover, it must be understood that adversaries will use asymmetric tactics and techniques to deny or exploit differences in technology, force size, information systems, or cultural factors. Hence, scenarios and analyses that deal with an appropriate set of all these dimensions should be considered in either the main research design or in the excursions to assess risks and uncertainty.

The evaluation of C2 issues depends in important ways on both distinguishing and linking dimensional parameters, measures of performance, measures of

C2 effectiveness, and measures of force and policy effectiveness. Modelling and other tools must be designed to support this requirement.

Tools and data used in C2 analysis should conform to good OA processes and practices and, to the extent feasible, should be subject to Model Verification, Validation, and Accreditation (VV&A) and to Data Verification, Validation, and Certification (VV&C).

Interoperable analytical infrastructures (e.g. data dictionaries, glossaries, models, tools, data sets) are necessary to facilitate the efficient proliferation and reuse of study results and data within the broader interdisciplinary research community.

Because the complexity of C2 and the requirements for its analysis are often underestimated by decisionmakers, a continuing dialogue between analysts and those decisionmakers is necessary both to scope the problem properly and to ensure that the analytic results are properly understood. Part of this process includes performing sensitivity analyses and other common practices designed to ensure the validity and reliability of the results.

Changes to C2 systems will often lead to changes in military concepts, command approaches, doctrine, Tactics, Techniques, and Procedures (TTP), and related factors, which must also be considered in the analysis.

Current State of Practice in C2 Analysis

Assessment of C2 issues typically employs classic tools of OA. Relatively few specialised tools and methods have been developed for C2. Moreover, those specialised tools generated to deal with the unique aspects of C2-focused research are generally not as well understood as those used in more traditional warfare modelling domains. C2 analysts will often find themselves having to develop tools and approaches appropriate for their research agendas. However, a general analytic process can be identified that will enhance the likelihood that an OA analyst can conduct successful analyses.

Organisation of the COBP

This COBP is organised into four themes. The first theme deals with study dynamics, problem formulation, and the development of a solution strategy. The second theme identifies and discusses in depth the essential elements of assessment: measures of merit, scenarios, human and organisational issues, data, and tools. The third theme addresses issues related to risk and uncertainty while the final theme describes the range of assessment products.

This represents a significant enhancement of the initial COBP. In particular the first, third and fourth themes were not treated in detail in the initial version of the COPB. In addition, material has been added to the second theme to address the unique assessment challenges associated with OOTW.

Brief History of SAS-026

SAS-026 builds upon almost a decade of work that began with the formation of the Ad Hoc Working Group on the Impact of C3I on the Battlefield 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 decisionmaking. 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), C3I Systems, Structures, Organisations, and Staff Performance Evaluations (Norway), and Models Used for C3 Systems and Analysis (US/UK). Representatives from the nations in parentheses took the lead in organising the workshops and summarising the results. The minutes of the workshops provide further illustrations of the techniques presented in the COBP.

At the October 1996 meeting, the group took up a request by Panel 7 to conduct a symposium on modelling and analysis of C3I, which was scheduled at the July 1997 meeting for January 1999. This symposium was a forum for presentation and discussion of the COBP and related topics.

At the July 1997 meeting, in response to a query by Panel 7, the group discussed, acknowledged, and agreed on the need for a follow-on group to SAS-002. An exploratory group on organisational change (SAS-E05) was formed to recommend a way ahead.

SAS-E05 recommended the formation for a follow-on activity to SAS-002 to accomplish four objectives:

- Demonstrate and assess the initial version of the COBP;
- Revise and extend the COBP;
- Identify research areas; and
- Facilitate the adoption of the COBP.

The SAS panel concurred in May 1999 and approved the formation of SAS-026, which began its 2 1/2-year plan of work in a symposium in January 2000.

Chapter 1 Acronyms

C2 – Command and Control

C3(I) – Command, Control, Communications (and Intelligence)

C4(I) – Command, Control, Communications, and Computers (and Intelligence)

C4ISR – Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance

CIS – Command Information Systems

COBP – Code of Best Practice

DP – Dimensional Parameters

MoCE – Measures of C2 Effectiveness

MoFE – Measures of Force Effectiveness

MoM – Measures of Merit

MoP – Measures of Performance

MoPE – Measures of Policy Effectiveness

NGO – Non Governmental Organisations

OA – Operational Analysis

OOTW – Operations Other Than War

PfP – Partnership for Peace

PVO – Private Volunteer Organisations

RSG-19 – Research Study Group-19

TTP – Tactics, Techniques, and Procedures

VV&A – Verification, Validation, and Accreditation

VV&C – Verification, Validation, and Certification

Chapter 1 References

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[1]As an illustration, General Colin Powell, then Chairman, Joint Chiefs of Staff, summarised the mission in Desert Storm by stating that "First, we will cut off the enemy and then we will kill it." (Pentagon Briefing, Wednesday January 23, 1991.)

[2]As an example, the US Congress has continually sought to impose an arbitrary deadline for US forces to withdraw from Bosnia.

[3]Mission capability packages include all of the elements necessary for an operation. (Alberts, 1996).

CHAPTER 2

Preparing For Success: Assessment Participants, Relationships, and Dynamics

For hypotheses ought…to explain the properties of things and not attempt to predetermine them except in so far as they can be an aid to experiments.

—Isaac Newton (1687)

We have run out of Money—now we have to think.

—Ernest Rutherford (1871-1937)

Overview

This chapter is organised into three parts. The first discusses the roles played by the significant players associated with a Command and Control (C2) assessment and how these roles affect the design and conduct of the assessment. The second part identifies the major phases of a C2 assessment and their iterative nature. The concluding section addresses the subject of professional ethics and standards of conduct.

Assessment Participants

Like their subject, the organisation of C2 studies involves complex interrelationships. It is crucial for the analytical team to establish which individuals and organisations are involved at an early stage of the study. It is prudent for the analytical team to map the roles described below onto the individuals and organisations involved and to understand their interrelationships. An example of such a mapping is at Figure 2.1. Appendix 1 to this chapter provides a brief explanation of the organisations involved.

Due to the dynamic nature of such projects, those involved should not be surprised if the nature of the teams involved might have to expand or change with time.

Assessment Team

The assessment team is working for the sponsor or client (sponsor). The team consists of a senior team leader (who may also be referred to as the project manager), a core set of analysts, subject matter experts including military officers, and supporting staff who are working on the study on a day to day basis. The team provide the legitimacy and authority for the study. The sponsor will provide the terms of reference, access to needed information, and identify the desired products. It is important for the analytical team to understand exactly why the sponsor wants the study and what the sponsor wants to do with the results.

Decisionmakers or Problem Owners

The decisionmakers are the individuals or organisations that are expected to make decisions wholly or partially based on the output or findings of the study. If there is no decision to be made (i.e. this is an exploratory study) then the decisionmakers could be referred to as problem-owners. It is important for the assessment team to understand exactly what type of assessment the decisionmakers want the study to support. The decisionmakers may or may not be in command of or part of the sponsor’s organisation. Complex problems may arise when the decisionmaker is several steps laterally away in the organisation from the sponsor and study team.

Stakeholders

The stakeholders are the persons or organisations that are directly or indirectly affected by the study outcome. Stakeholders may also play other roles. The assessment team must be aware of the potential for conflict when the stakeholders do not include the sponsor or decisionmaker. Complex problems may arise in the provision of data for the study, as it is the stakeholders who may have to provide the data, set the security or releasibility of that data (and hence the study), and/or agree that the data are representative. For these reasons it is essential that the analysts establish a working relationship with the stakeholders early in the process.

Bill Payer

The bill payer is the organisation or individual official paying for the study. It is important for the assessment team to know the level of resources available. Bill payers will normally have a direct interest in the outcome of the study and may be one or more of the other players. Contractual authorities have the legal authority to let contracts on behalf of the bill payer.

Existing Study Teams

The assessment team must be aware of and sensitive to the existence of teams in other related study areas. Should such teams exist, the assessment team should endeavour to exploit the work done and available skills and techniques. Such external teams may also be appropriate for membership in peer reviews.

Future Study Teams

The assessment team must be aware of and sensitive to the needs of future analyses and assessments. Data collection, method documentation, and the archiving of data, methods, models and results are fundamental responsibilities of all professional analysts. Method and data should be (as far as is practicable) disseminated and published.

Peer Reviewers

Outside experts brought in to look at the work and provide constructive criticisms are called peer reviewers. Peer review teams could be composed of specialists and other study teams in related subject areas and should include representatives from all key disciplines in the assessment.

Data Providers

Data providers are the individuals and organisations that possess data and information useful to the assessment team. Many of these will be stakeholders. The motivation to provide data to the study must be developed by the analytical team and the sponsor.

Assumption Providers

Assumption providers are the individuals or organisations that can provide "givens" such as future doctrine, performance data, force mixes, organisational structures, and scenarios. Creation of a positive relationship with these organisations is important to the study.

Data Collectors

In some C2 analyses, where data must be extracted from real world experiences, exercises, experiments, and wargames, teams of data collectors and subject matter experts will be required. The identification of people with the appropriate background and training as data collectors is an important element of such studies.

Relationships Among Participants and the Conduct of the Assessment

Relationships

Figure 2.1 illustrates how complicated the participant roles and relationships can be in a real C2 assessment. This particular figure represents the organisations involved in the recent Immediate Reaction Task Force (Land) (IRTF(L)) C2 Concept evaluation that completed at the end of 2001 (Candan & Lambert, 2002). Appendix 1 to this chapter provides a brief explanation of the organisations involved. Although not all projects will be this complex, many important C2 assessments will.

Through the prudent act of mapping the roles of the participants of the study, the potential conflicts of interest and complex interactions can be identified. One method to mitigate these is to present or conduct this activity openly and discuss with all involved so that all potentially affected participants are aware of the possibility of future conflict and the fact that all participants fall into one or more roles within a project.

In the event of conflict with other participants in the project the assessment team should address the issues in a neutral and independent manner.

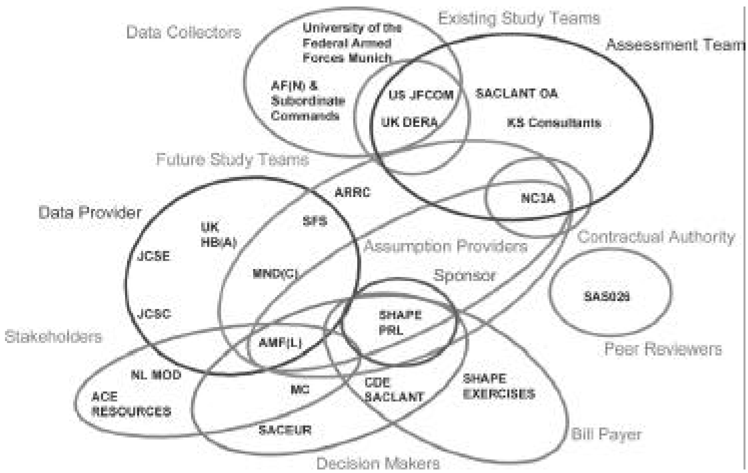

Figure 2.1. Example of the Mapping of Roles onto Players—for a Complex C2 Project (the Evaluation of Immediate Reaction Task Force (Land) C2 Concept)

Understanding the Context of the Assessment

The relationship among the assessment team, the key sponsor, and the stakeholders is of paramount importance and perhaps, more than any other single factor, will influence the course and success of the effort. Accordingly, adequate attention needs to be paid to understanding the situation facing the key sponsor and stakeholders as much as the subject under study.

The assessment team should be aware that the different participants will have divergent perspectives and may have divergent agendas.

Therefore the assessment team should understand the background of the individuals involved, their organisational settings, roles and responsibilities, their history, and their current situation. Contact with analysts who have worked with this sponsor and review of prior analyses for this sponsor facilitate this objective.

It is good practice to build and maintain long-term relationships with the sponsor and stakeholder organisations. This will yield substantial dividends in the form of easier communication, greater trust, and stronger support.

A Continuing Dialogue

It is important that a dialogue with the sponsor and stakeholders is maintained by the assessment team throughout the study. As there is no single “language” that will describe the study problem, it is important to spend time at the beginning of a study to establish a common “language” that both the assessment team and the sponsor and stakeholder can understand. This point may seem obvious in a NATO setting in which the participants speak many different natural languages. However, it is equally important in a single language setting because common words and phrases have different meanings for different organisations, services, and even individuals within a single organisation. Regular meetings and contact will minimise misunderstandings. From a professional point of view, Operations Research (OR) and Operations Analysis (OA) analysts will always wish to inform the sponsor and stakeholders of key developments and/or challenges as the study unfolds. Regular and routine interactions need to be built into the project plan. If there are multiple sponsors and stakeholders and other key actors, the assessment team should try to meet them jointly, particularly when decisions need to be made. Separate meetings will often lead to inconsistent guidance and will place the assessment team in a position of trying to accommodate differing interests.

The development of a collectively agreed upon Study Glossary that captures the definitions of words, phrases and acronyms used in the study is a useful tool.

Terms of Reference

A good "term of reference" covers goals, scope, products, schedule, and resources. These will determine the focus of the assessment and establish limits or freedoms granted to the assessment team within the sponsor's and stakeholder's organisations. Letters of introduction and instructions to actors within the sponsor and stakeholder organisations may also be useful.

Understanding How the Output of the Study Will be Used

It is important to know at an early stage in the project what the products of the study are to be used for by the sponsor and stakeholder organisations. The expected end product will set the tone and relative importance of the project in the eyes of the sponsor, stakeholder, and other actors. The assessment team needs to establish and understand the products needed or desired by the sponsor and stakeholder. For example, a study could be used to create a significant impact on the stakeholder's domain, gain a greater understanding of the issues, produce an improved capability to perform future work, and/or make contributions to the body of knowledge.

Budget

The sponsor will have limited resources with a study budget in mind. When the sponsor's resources are limited to a level below what is required to support a quality study, the assessment team will need to suggest strategies to address the shortfall. Alternative approaches include decomposing the problem and only undertaking the core part of the study that is affordable, linking the sponsor to other actors that have an interest in the same or a similar problem and who could contribute resources, and/or stretching the project over a longer time so that resources from future budget cycles become available. In developing strategies that involve doing only a part of the study to satisfy budget constraints, care must be taken to ensure that the product that will be produced provides a meaningful answer or contribution and does not depend upon a follow-on effort that may or may not be funded.

It may take a complete iteration of the assessment phases of the project to establish the complete scope of the project and the resources required. Therefore it is good practice in large C2 projects to allow the assessment team to perform a rapid first pass of all the phases of the project to help establish the budget required. This is contrary to the usual practice of setting the budget in stone immediately following the initial Problem Formulation or Solution Strategy phase (see Section 2-E below).

Relationships

Figure 2.1 illustrates how complicated the participant roles and relationships can be in a practical C2 assessment. This particular figure represents the organisations involved in the recent Immediate Reaction Task Force (Land) (IRTF(L)) C2 Concept evaluation that completed at the end of 2001 (Candan & Lambert, 2002). Although not all projects will be this complex, many important C2 assessments will be.

Building an Assessment Team

Skills Available to the Assessment Team

Following initial problem formulation (Chapter 3), the precise skills and experience required by the assessment team will need to be established. Typically, the assessment team will need to be interdisciplinary. The wide range of skills and experience required can be allocated between a full-time core team and a collection of consultants or part-time team members. As an example, an ideal breakdown of the skills available to the assessment team involved in the evaluation of the Immediate Reaction Task Force (Land) C2 concept study[1] is given below:

Skills: Core Team

- Project management;
- OR/OA skills: simulation, wargaming, mathematical programming, database creation and management, brainstorming and problem

structuring, scientific/military report writing/ editing;

- Cross military experience—i.e., OR/OA personnel with military experience or military personnel with OR/OA knowledge;
- Organisational theory; and
- Data collection (e.g., questionnaire and form design).

Skills and Experience: Consultants and Part-time Team Members

- Military (or access to practical experience of problem under study);
- Training and exercise planning (if an exercise is to be used as a vehicle for the study);
- Communications and information systems specialists for the systems of the organisation under study;
- Human computer interface expertise;
- Operations Other Than War (OOTW) related issues (e.g., C2/Headquarters [HQ], media, civil-military cooperation—theory and practice);
- Social scientists (e.g., political, psychological, economic, cultural, legal);
- Military history;
- Command experience;
- Deployment analysis;
- Intelligence/threat/area of operations expertise; and

- Legal/contracts/administration expertise.

As another example of the skills required for C2 Assessment Studies, the skills required to provide OR support to C2 elements (such as OR/OA support to an operational HQ) is also analogous, as illustrated in Table 2.1 (RTO, 1999).

Key Areas	Knowledge, Capabilities, and Skills Required	
Analytical	Probability theory Parametric and non-parametric statistics Force and systems modelling Traditional OR techniques[2] Decision tools	Management tools Organisation theory Information management Process engineering Systems dynamics
Military	Understand military staff Staff organisation	Civil-military affairs Situation appreciation
Inter-Personal	Interpersonal skills Instructor skills	Consultant skills Writing and presentation skills
Software Competencies	Word-processing Spreadsheets Presentation Databases Mapping Plus other speciality systems	Project management Mail systems Network systems World wide web Programming language
Hardware Expertise	Computers Printers Scanners	Peripheral devices Networks

Table 2.1. Knowledge, Capabilities and Skills Needed by OR/OA Cell Team Members

Background of the Assessment Team

Building a C2 assessment team with this full breadth of knowledge, capabilities, and skill requires a long-term commitment by the mother OR/OA organisation to prepare a corpus of potential team members through recruitment, education, training, and opportunities for appropriate field experience.

Following the identification of the skills required for the team, those analysts made available for the team should ensure that they leave a basic understanding of the military fields under consideration. Gaps in experience should be rapidly filled through background reading, short courses, field experience, or additional/

alternative analysts with the appropriate experience and skills.

Forming the Assessment Team

In a study that involves dispersed and disparate organisations and teams, the effort to command and control the study group must be recognised and effort and time built into the study plan. This can be, for example, through maintenance of distributed working environments such as web portals, information campaign material and travel time to meetings. In these cases the senior team leader will revert to a role more akin to a project manager.

It is one thing to assemble a group of people, quite another to forge them into a coherent effective team. Sufficient time and a facilitating process should be built in to the project plan for the group of individuals to coalesce into a team.

Interdisciplinary Assessment Team and Outside Relations

It follows that C2 analysis, particularly for OOTW issues, should be done by an interdisciplinary assessment team. Experienced analysts know that their work owes success in no small measure to efficient working relationships within the assessment team and with the customer of analysis. Building good working relationships among representatives of different scientific cultures, such as OR/OA and IT analysts grounded in (hard) physical sciences and mathematics on one hand and (soft) social scientists on the other, requires sufficient mutual understanding of methodologies and tools. In fact, differences in scientific cultures can outweigh differences in natural cultures provided that all members of the assessment team have sufficient command of a common language. Therefore, in addition to leadership and project management skills, the head of the assessment team must have a good general idea of the current state of all disciplines involved in order to compose an efficient team and facilitate interdisciplinary cooperation throughout the analysis.

Good personal and working relationships with the customer of the analysis are essential for understanding every aspect of the problem and being able to arrive at a problem structure and solution strategy that meets the customer's immediate needs in the light of the strategic objectives of the respective OOTW. Knowing the customer's position in the command hierarchy and the degree of influence he/she wields through informal relationships over stakeholders and actors, the co-operation of which might be essential for an implementation of analysis results, and understanding the respective consequences associated with alternative solutions is important for assessing their acceptability and organisational risk.

It is equally important for the assessment team to establish working relationships with the potential subjects of study in the early stages. This is essential for capturing the nature and problem relevance of formal and informal relations between all organisations, groups, and individuals that are subjects of the study, finding out about their motivations and agendas, and eliciting firsthand information that is critical for solving the problem such as their capabilities and the conditions attached for their employment. However, the analyst should be careful not to allow this effort to gain greater understanding of the problem to introduce bias.

Assessment Phases, Process, and Dynamics

It is important to realise that all of the elements of the C2 assessment are interrelated. Hence Problem Formulation, Solution Strategy, Measures of Merit, Scenarios, Human/Organisational Factors, Models/Tools/Data, and products are all interdependent. Figure 2.2 illustrates the major phases and iterative nature required for C2 assessments. The Assessment Process diagram was the most difficult thing for the SAS026 team to agree upon. In essence this diagram is at the heart of the COBP (Starr, 2001). The remainder of this chapter discusses the key points in this diagram.

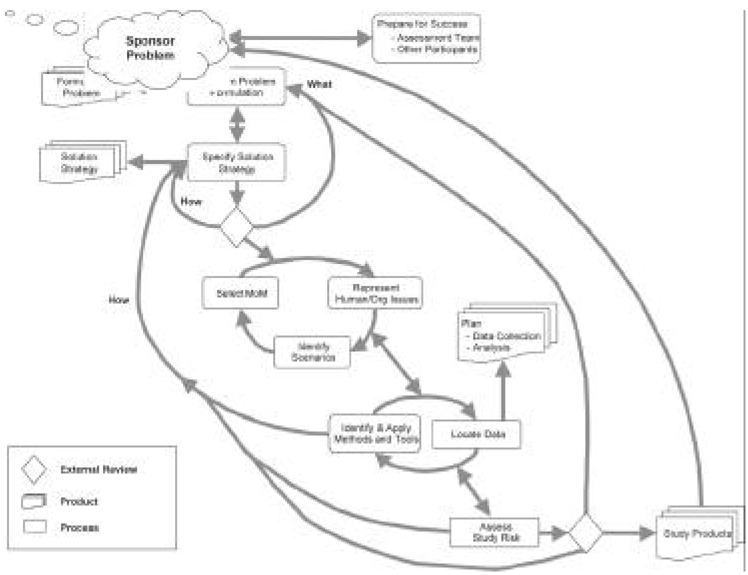

Figure 2.2. C2 Assessment Process

Problem Formulation

The output of Problem Formulation (Chapter 3) specifies the "what" of the assessment. C2 studies tend to be complex and feature multiple attributes, some of which may not be apparent at the start of the study. Neither the assessment team nor the sponsor should be surprised if the issues initially presented for study are replaced by other issues that are closer to the underlying causes of the initial problem or, in some cases, symptoms presented. A consequence of the dynamic nature of problem formulation is that the solution strategy and any of the other elements of the assessment may change as the study progresses. Problem formulation should therefore be consciously and routinely iterated during a study—especially when new attributes start to appear. As a minimum an iteration should occur immediately following the establishment of the initial solution strategy and the assessment of study risk. Additionally, the sponsor should be aware that the nature of the assessment team, sponsor, or assumption provider teams might also have to expand or change with time. This has implications for planning, budgeting, and tasking.

In nearly all C2 studies the assessment team will study only a subset of the whole problem space due to the sponsor's sphere of interest. This fact must be recognised by the assessment team. An initial study of the complete problem space is essential to establish this realisation. This will help the assessment team to understand the context of the study and provide advice to the sponsor on the actual underlying causes to his problem and consequently the requirement to involve other participants.

Solution Strategy

The next step is to develop a Solution Strategy (Chapter 4) that specifies the "how" of the assessment. Arising from the Solution Strategy agreed upon and adopted by the sponsor are a set of terms of reference (e.g., Statements of Work [SOW] for contracts) that will determine what work is to be conducted, the contractual obligations, deadlines, and resources. Although these must be established as an experimentation campaign plan[3] and study management plan (project plan) before work on the project begins in earnest, flexibility must be built-in due to the iterative nature of C2 assessment. The assessment team must be aware of any preconceived "solutions" that have been proposed by the sponsor, stakeholders, and/or decisionmakers and explicitly deal with these as appropriate, avoiding another pressure to be steered in a particular direction. The assessment team must note if its results are being steered in a particular direction and follow ethical behaviour in performing the study (see the end of this chapter). In many cases a risk-based approach to C2 assessments can usefully complement the more traditional cost-effectiveness approach. In particular, this helps decisionmakers to deal with the uncertainties of the real problem.

From a professional point of view analysts should always defer the selection of a particular method until the problem has been formulated and a solution strategy has been defined. Recognise and beware of "preconceived" solutions that could influence the assessment.

Review

Once there has been a preliminary formulation of the problem and development of a solution strategy, it is imperative that an initial review be conducted. This review should be conducted from multiple perspectives (e.g. with respect to the sponsor's initial problem, the feasibility with respect to resources including team skills and schedule, soundness of the proposed analytic approach). As a result of this review, changes will usually be made in both the problem formulation and the solution strategy.

Measures of Merit, Scenarios, and Human/Organisational Factors

At this stage the assessment team must specify the hierarchy of Measures of Merit (MoM) (Chapter 5), incorporate and identify relevant human and organisational factors (Chapter 6), and specify the appropriate scenarios (Chapter 7). As suggested by the diagram, there is no unique sequence for doing these tasks. Iteration is required to ensure that these tasks are done in a coherent, consistent fashion. When all of these tasks have been completed, the team has specified the key variables to the necessary level of detail with adequate considerations for assessment validity and reliability.

When developing the MoM it is very valuable to involve the sponsor in establishing the linkages between the MoMs and the hierarchy of MoM. This is because then the sponsor will then appreciate the dynamics of the problem and the requirement for breadth in the study. Although a full set of MoM must be derived in accordance with the best practice noted in Chapter 5, the MoM should be prioritised to focus on providing support to the objectives of the study and be practical and cost effective.

When selecting appropriate scenarios it is good practise to utilise scenarios (if they exist) from a standard set of scenarios approved for use within the assessment and sponsor organisation. The sponsor must always be approached for approval of the scenarios. It is bad practice to design a scenario to prove a point.

Models, Tools, and Data Requirements

The next step is to iteratively identify the methods and tools (Chapter 8) and data (Chapter 9) required to perform the assessment. One of the major challenges of the assessment is to identify and gain access to models, tools, and data that are appropriate for exploring the issues of interest. The challenges come in several dimensions:

- First, there is a limited set of tools that deal effectively with the C2 dimension of the problem.
- Second, for even this limited set, it is often difficult to access and modify the tools to reflect the variables of interest.
- Third, there is often a paucity of useful data and previously validated parameters.

As a result of the establishment of the MoM for the study and the data that underpins those MoM and models, a data collection and analysis plan should be formulated. The sponsor should also be made aware of the difficulties associated with getting appropriate data, cost of the data collection and analysis plan, and the implications to the study if the required resources are not set aside and budgeted to collect, collate, process, and analyse the data.

Assess Study Risk

At this point in the process the assessment team should take a look at the risks and uncertainties (Chapter 10) associated with the decisions made with respect to all of the tasks performed to date (e.g., consistency between the scenarios and the data, models and availability of data, tools and analysis). The sponsor must be made aware of these risks and uncertainties and the strategies developed by the team to mitigate them. If the risks associated with the successful completion of the study are perceived as being too high, the solution strategies should be revisited and adjusted accordingly.

Peer Review

When the risk and uncertainties are perceived as manageable, a peer review should be conducted. Peer reviews are not used enough because they tend to be time-consuming, seen as raising costs, or perceived as threatening. In addition, research teams often want to perfect their results and methods before revealing them. The key is to build a peer review into the study from the outset. The sponsor should be informed as to the importance of the peer review. Peer reviews should be built into the budget and reviewers invited to look at the terms of reference, interim products, and draft reports so that they are knowledgeable about the effort and motivated to support the project. In later stages of the study, the peer review can improve presentation and also act as a mechanism to make the results known to the professional communities. Over time the assessment team should develop a relationship with high quality peers and use them as a pool of reviewers.

Peer reviews are not a luxury but a necessity.

Conduct of the Study

At this point we are in a position to execute the assessment. The assessment team leader should keep a study notebook or journal in which all assumptions and decisions are documented so that they are available for detailed discussion. Detailed administrative records need to be kept regarding the data, metadata, models, and analytical and documentation tools. This will enable replication of parts of the C2 analysis should the need arise. An effort should be made to create data sets (not just the project results) that will be available to other researchers. The resources required to make such data available to external bodies needs to be made clear to the sponsor. The conduct of the study will not usually be linear. It should be anticipated that multiple iterations will be conducted and that lessons learned from initial data collection and analysis efforts will inform subsequent activities.

Study Products

The team must recognise the importance of presenting the results of the assessment in a clear and comprehensive manner, taking into consideration the style of the decisionmaker (Chapter 11). It is particularly important that these results illuminate rather than obscure the uncertainties associated with the assessment.

Ethics

Professional operations research organisations, such as the Military Operations Research Society (MORS), have developed professional codes of ethics (Annex C). The assessment team should also be guided by a set of professional ethics and standards of conduct to ensure the integrity and quality of the analysis. This means that the assessment team should, inter alia:

- Maintain an open and honest dialogue with the sponsor and other key players within the project in order to minimise misunderstandings;
- Ensure that C2 assessments are organised and conducted in a balanced fashion that adequately identifies and represents all perspectives, options, and relevant evidence;
- Inform the sponsor and other key players of:
    - any constraints, assumptions, or circumstances that threaten a balanced assessment; and
    - the risks and uncertainties associated with the methods and data used in the project, and
    - strategies to minimise the risks.

Chapter 2 Acronyms

ACE Resources – Allied Command Europe Resources – (Part of SHAPE)

AF(N) – Regional Command (North)

AMF(L) – ACE Mobile Force (Land)

ARRC – ACE Rapid Reaction Corps.

C2 – Command and Control

CDE – Concept Development and Experimentation

CPX – Command Post Exercise

FTX – Field Training Exercise

HB(A) – UK Historical Branch (Army)

HQ – Headquarters

IRTF(L) – Immediate Reaction Task Force (Land)

JCSC – Joint Sub-Regional Command South Centre

JCSE – Joint Sub-Regional Command South East

JFCOM – US Joint Forces Command

KIBOWI – NL Army Exercise Driver

MND(C) – Multinational Division (Central)

MoM – Measures of Merit

MORS – Military Operations Research Society

NC3A – NATO C3 (Consultation, Command & Control) Agency

NL MOD – Netherlands Ministry of Defence

OOTW – Operations Other Than War

OA – Operational Analysis

OR – Operations Research

PRL – SHAPE Policy Requirements Land

SACLANT OA – Supreme Allied Command Atlantic Operational Analysis Cell

SFS – Strike Force South

SHAPE – Supreme HQ Allied Powers Europe

SOW – Statements of Work

WPC – Warrior Preparation Center (Ramstein Germany)

Chapter 2 References

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Appendix 1 to Chapter 2: Participant Mapping of the Evaluation of the Immediate Reaction Task Force (Land) C2 Concept—An Explanation of Figure 2.1

Background

The Immediate Reaction Task Force (Land) (IRTF(L)) command and control concept was proposed in 1998 as a mechanism to modernise the ACE Mobile Force (Land) (AMF(L)). The IRTF(L) concept is predicated on the enlargement of AMF(L) from brigade size up to division size with a single streamlined headquarters and a chain of command using embedded mini-Task Group HQ cells. This was evaluated between 1999 and 2001 as a test case for the NATO Concept Evaluation and Experimentation (CDE) process using a series of FTX, CPX, wargames, simulations and historical analyses.

Assessment Team

In the case of the IRTF(L) study the assessment team was led by NC3A OR Division, with contracted experts, analytical and military support from KS Consultants and UK DERA. Free analytical support was also made available at peak periods from US JFCOM and SACLANT Operational Analysis (such as the exercises of the experimentation campaign).

The sponsor was SHAPE Policy and Requirements Land—who were tasked with the evaluation of the C2 Concept.

It was clear to the assessment team as to why the sponsor wanted the study—a straightforward evaluation of the military utility (to NATO) of the C2 Concept. However at the end of the study the results were combined with other issues, and decisions were made on the future of the unit under study. This was something that was not foreseen by any of the participants at the start of the project.

Decisionmakers or Problem Owners

The sponsor's task was to provide advice up the chain of command to SACEUR and ultimately the Military Committee on the efficacy of the C2 Concept. Although the HQ ACE Mobile Force (Land) was the subject of the study it was also party to any decision regarding its own future modernisation. It is commanded directly by SACEUR via SHAPE.

SACLANT CDE, however, was not in the command chain, but was seen as a decisionmaker within the context of the study as it was interested in the experience of the team in conducting the study as a test case to illustrate the value of NATO Centred CDE to the Alliance.

Stakeholders

The ACE Mobile Force (Land) was the main stakeholder as it was the subject of the study. As a decisionmaker, data and assumption provider and also possible member of a future study team it was in a very powerful position, and was approached and treated with much respect by the assessment team. After a shaky start (where neither side was sure of the other's intentions) a good working relationship was established over the period of the project.

The Netherlands MOD—in the form of the Royal Netherlands Army—was the provider of the Command Information System (ISIS) used as the digitisation vehicle for the evaluation of the concept. As such it was directly affected by the exercise program used for the experimentation and also the future of the concept and AMF(L).

The Military Committee was also a stakeholder, representing the Nations of NATO that contribute troops and staff to the AMF(L), and these nations would be directly affected by any decision on the concept.

ACE Resources at SHAPE were also a stakeholder as they were required to sanction and organise any manning changes proposed for the HQ—including the temporary additional manning required for the evaluation.

Bill Payer

Monies were mostly provided from the slice of the NC3A Scientific Program Of Work (SPOW) controlled by SHAPE PRL. In the initial stages of the project additional monies were also provided by SACLANT.

Monies also had to be sought from the SHAPE Exercise budget to pay for movement of the exercise observers in order to attend the exercises.

Throughout the project the NC3A was the contractual authority to let contracts on behalf of the bill payer.

Existing Study Teams

An extensive literature search was conducted for the study—with the majority of recent references occurring within the UK and US. Exploratory trips (organised through US JFCOM) to US Battle labs and UK facilities (through UK DERA) revealed the current state of knowledge with respect to measuring C2 performance in exercises and evaluating new C2 concepts. In response to this the data collection methodology was based initially on the Fort Leavenworth, US Army Research Institute ACCES method.

Future Study Teams

It was identified at an early stage that there could be future related projects. In particular those relating to expeditionary and initial entry forces. The probable NATO organizations that could be involved in such studies were NC3A, SHAPE PRL, AMF(L), Multinational Division (Central), Strike Force South and the ACE Rapid Reaction Corps. Of course there would probably be future study teams within the nations—but these plans are not visible to NATO. Consequently, as the assessment team was very likely to be involved in such future work; all data was archived and routinely written up and published.

Peer Reviewers

The assessment team were not able to arrange a formal Peer Review of the solution strategy adopted. This mechanism does not yet exist for NATO centred studies. What was achieved the submission of the problem to the SAS026 panel as an example for testing the coverage of the revised COBP. This yielded some practical advice and helped the assessment team better understand the dynamics of the project.

Data Providers

Most of the data for the evaluation were derived from NATO training exercises run by or for AMF(L), MND(C), SFS and Joint Sub Regional Commands South East and South Centre. In all cases relationships had to be curried by the assessment team and sponsor to allow access to the HQ and Exercise Control for the exercise observers, and for background materiel. In two cases national exercise training centres and exercise drivers were hired by the assessment team to support command post exercises (Warrior Preparation Center, and the KIBOWI exercise driver). Historical data for the study was also provided from the UK Historical Branch (Army)—which was approached via the contracted UK members of the assessment team.

Assumption Providers

The assessment team was in the fortunate position to actually be one of the assumption providers—through NC3A's and the sponsor's involvement in the NATO Defence Requirements Review. The owner of the C2

Concept however remained HQ AMF(L) itself, and therefore remained the authority as to its conceptual and physical implementation.

Data Collectors

In the case of the IRTF(L) study, data was largely extracted through observation of HQ activities during exercises and team-in-the-loop wargames. In all of these exercises Subject Matter Experts (SME) were used to observe functional and cross functional activities in the HQ. Most of the military SMEs were provided by Regional Command AF NORTH and its subordinate commands across Allied Command Europe (ACE). Additional data collectors were also provided by the German University of the Federal Armed Forces and US JFCOM. UK DERA provided military analysts to lead some of the activities involved in capturing the HQ processes.

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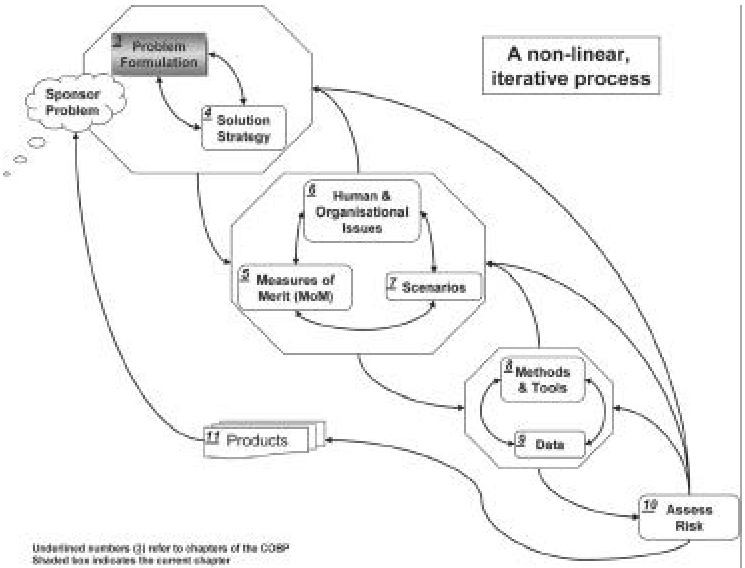
[1]As developed independently by the SAS-026 panel in February 2001 in response to a presentation in the IRTF(L) project. In fact, this was fairly close to what was available to the team.

[2]Linear programming, dynamic programming, queuing theory, inventory control, network analysis with PERT, game theory and simulation.

[3]Required if the C2 Assessment makes use of a series of linked events such as seminars, wargames, command post exercises (CPX), field training exercises (FTX), etc.

CHAPTER 3

Problem Formulation



First find out what the question is—
then find out what the real question is.

—Vince Roske

Definition of Problem Formulation

Effective problem formulation is fundamental to the success of all analysis, but particularly in Command and Control (C2) assessment because the problems are often ill-defined and complex, involving many dimensions and a rich context. Problem formulation involves decomposition of the analytic problem into appropriate dimensions such as structures, functions, mission areas, command echelons, and C2 systems. Problem formulation is an iterative process that evolves over the course of the study. It is essential even for small studies or where time is short—it will save time later and help ensure quality.

The problem formulation phase should identify the context of the study and aspects of the problem-related issues.

The context of the study includes:

- Geopolitical context that bounds the problem space;
- Political, social, historical, economic, geographic, technological environments;
- Actors;
- Threats;
- Aim and objectives of the analysis, including the decisions to be supported;
- Generic C2 issues;[1]
- Relevant previous studies; and
- Stakeholders and their organizational affiliation (including both stakeholders of the problem and stakeholders of the study).

The aspects of the problem include:

- Issues to be addressed;
- Assumptions;

- High-level Measures of Merit (MoM);
- Independent variables (controllable and uncontrollable);
- Constraints on the values of the variables (domain and range);
- Time constraints on delivery of advice to the decisionmaker; and
- Whether this is a single decision or (possibly one of) a chain of decisions to be made over time.

The problem is not formulated until the assessment team has addressed each aspect of the problem. In simple terms, problem formulation can be seen as an iterative process. First, the team must identify the variables that bound the problem space. Then they must determine which of these are outputs (dependent variables) and which of these are inputs (independent variables). The team proceeds by iterating to build an understanding of how these relate to each other. It should be viewed as a voyage of discovery. In most, if not all, cases of C2 assessment, the knowledge domain under study is in fact a system characterised by rich interaction and feedback among all the factors or variables of interest. The choice of dependent variables results from a clear specification of the issues and products needed to satisfy the terms of reference. Independent and intervening variables are also chosen based on the purpose of the analysis.

In the initial problem formulation iteration, it is critical to begin with an understanding of the REAL problem rather than a determination to apply readily available tools, scenarios, and data.

Within the NATO context, a number of documents are available or under development that may assist in understanding the study context. They are listed at the end of this chapter.

Principles of Problem Formulation

There is no universally acceptable approach to problem formulation. However, best practices exist that can be applied. The principles associated with problem formulation are addressed in two categories: those that are appropriate for all C2 assessments and those that are appropriate for assessments of C2 for Operations Other Than War (OOTW).

Principles Appropriate for C2 Assessments

Explicit problem formulation must precede construction of concepts for analysis or method selection. This is not a trivial exercise, especially in C2 assessments. Proper resourcing of problem formulation activities will improve the overall efficiency and quality of the study.

An understanding of the decisions to be supported by the analysis and the viewpoints of the various stakeholders (e.g., customers, users, and suppliers) is essential to clarifying the study issues. This understanding should be fed back to the stakeholders. A careful review of previous and current work must be carried out as a valuable source of ideas, information, and insight. This review should also serve to identify pitfalls and analytic challenges.

Problem formulation 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. The formulated problem is thus an abstraction of the real problem that can be defined in terms of dependent variables that relate to this real problem and coherent settings for the independent variables that can be interpreted in terms of decisions and actions by the customer.

Problem formulation must be broad and iterative in nature, accepting the minimum of a priori constraints and using methods to encourage creative and multi-disciplinary thinking, such as proposing a number of hypotheses for the expression of the problem. It must be recognised that change is inevitable in many dimensions (e.g., understanding of the problem, requirements, technologies, co-evolution of concepts of operation, command concepts, organisation, doctrine, systems). Thus the assessment process must anticipate and accommodate this change.

Practical constraints such as data availability, study resources (including time), and limitations of tools should be treated as modifiers of the problem formulation rather than initial drivers. Such constraint may, in the end, drive the feasible solutions, but it is important to recognise this as a compromise rather than an ideal. *Proper problem formulation takes substantial time and effort!*

It is important that problem formulation address risk from multiple perspectives. In addition to sensitivity analysis of the dependent variables, risk analysis techniques should be used to directly explore options to mitigate risk (Chapter 10).

C2 assessment often involves impacts on defense business outside the context of a particular campaign or operation. The study must address these impacts.

Principles Appropriate for OOTW C2 Assessments

Problem formulation must address the geopolitical context of the problem and seek to identify the "broad" C2 issues contained within the terms of reference for the study. There are no universal societal "norms." Therefore, care must be taken in attempting to transfer the experience in one OOTW to another.

OOTW C2 assessments often involve policy-related impacts outside the context of a particular military operation. Therefore, MoM hierarchies must contain measures of policy effectiveness.

An historical perspective is critical to understanding OOTW because social conflict and structures often have roots far back in history. However, it must be remembered that present-day social behaviour is not driven by historical events themselves, but by present-day perceptions, processes, and prejudices which have evolved from the past.

A key risk in complex OOTW studies is allowing the problem formulation process to focus prematurely on subsets of the problem because they are: a) interesting; b) familiar; c) pre-judged to be critical; or d) explicitly called out by the customer. This requires great discipline by the study team, especially where the team's previous experience is biased in favour of particular parts of the problem space. *The assessment team needs access to subject matter experts from a broad range of* *disciplines (e.g., social scientists, historians, and regional experts in OOTW assessment).*

Problem Formulation Process

During the early stages of problem formulation it is important to quickly cover the whole problem and produce an initial formulation (i.e., an explicit expression of the problem) (See Figure 3.1). This prevents premature narrowing of the assessment and serves as an aid to shared situation awareness within the study team.

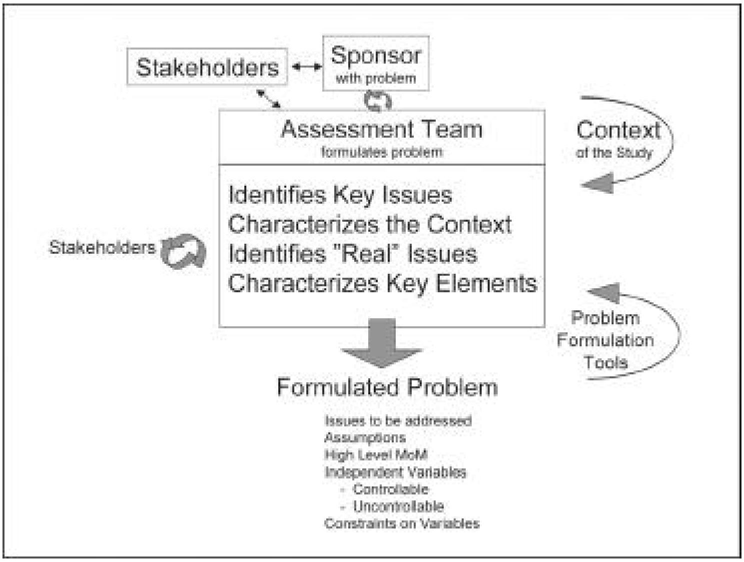


Figure 3.1. The Formulated Problem

The process begins with the sponsor presenting the assessment team with a problem to assess and an articulation of broad constraints (e.g., schedule, resources). Based on a preliminary assessment of the problem, the team identifies the key issues to address.

This identification of key issues leads to a characterisation of the context for the study (e.g., relevant geopolitical factors, identification of the key actors and threats, identification of generic C2 issues, review of prior studies). Based on the results of this characterisation, the analysis team identifies what it perceives as the *real* issues to address. It is vital for the team to engage in a dialogue with the key sponsor and stakeholders to get "buy in" for these issues. Once that is achieved, the team must identify and characterise the remaining elements of the problem formulation phase. To facilitate that activity, the analysis team should identify/create and apply selected problem formulation tools and techniques (e.g., brainstorming, Delphi analyses, directed graphics, influence diagrams). The results of that activity will include a summary of the assumptions, high-level MoM, independent variables (both controllable and uncontrollable), and constraints on the variables. Once it is coordinated with the sponsor and stakeholders, the end product documents *what* is to be done in the analysis. The next key activity will be to develop a solution strategy that describes *how* the study is to be done.

Bounding the Problem/Issues and Assumptions

In dealing with fuzzy or uncertain boundaries, the problem formulation process needs to explore and understand the significance of each boundary before making (or seeking from customers) assumptions about it. This involves keeping an open mind, during the early stages of problem formulation, about where the boundaries lie and their dimensional nature. This is difficult because it makes the problem modelling process more complicated. A call for hard specification too early in the problem formulation process must be avoided. In the end, of course, the problem must be formulated in order to solve it, but formulation should be an output from the first full iteration, not an early input to it.

In formulating an OOTW problem, we are trying to bound a complex system. This is partly a process of understanding boundaries which exist in reality (e.g., mission statements, geographical areas and the timing of a procurement process) and partly imposing artificial boundaries in order to illuminate the structure of the problem and constrain the scope of the analysis. To avoid the trap of over-specification, boundaries (especially self-imposed ones) should be kept porous, allowing for cause and effect chains to flow through the external environment of the portion of the complex system that the boundaries define.

While clear definitions and hard conceptual boundaries are ultimately necessary in order to create a manageable problem space, care must be taken to avoid coming to closure prematurely.

High-Level MoM

Identification of high-level MoM should 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).

A structured analysis of potential benefits[2] should be carried out as a basis for constructing appropriate

MoM. Mapping techniques, such as cognitive and causal mapping, are a good way to express the various relationships within the problem space and to identify ‘chains’ of analysis (i.e. links among the independent variables and between the independent and dependent variables). These lead to resultant structure in terms of independent and dependent variables, and hence to high-level MoM.

Problem Formulation Tools

It is useful to identify, develop (if necessary), and apply appropriate tools to support problem formulation. Representative tools and techniques include: techniques for supporting expert elicitation, influence diagrams, causal maps, system dynamic models, and agent-based models.

Problem Formulation is fundamentally a social process of developing a shared understanding. People skills such as the ability to facilitate a ‘brainstorming session’ or to elicit information and context, are thus important. ‘Throwaway models’ (which may be simple simulation models, causal maps, system dynamic models, etc.) may be developed as part of the process, and then discarded as insight is gained.

Tools and approaches used for problem formulation must be consistent with other tools and techniques likely to be considered for the subsequent analysis in order to produce a sensible ‘multi-methodology’ approach to the entire problem and its solution.

Constraints on the Variables

The formulation of the problem is completed when the constraints on either the independent or dependent variables have been identified. Constraints on the dependent variables represent "acceptable" thresholds or limits. For example, one could place a constraint on blue loss, time to accomplish a mission, collateral damage, or some combination of factors. Constraints on the independent variables represent either feasible or acceptable limits on such factors as human performance, C2 system performance, or even supplies. They also could represent doctrinal or legal processes that act as constraints.

The Next Step

The next step in the C2 assessment process is the development of a solution strategy. It should be noted that the team is not finished with problem formulation at this point but is now ready to proceed to build a solution strategy. As work progress on the development of a solution strategy, it will also certainly be necessary to revisit the specification of high-level MoM and the constraints. This chapter concludes with a discussion of the products of problem formulation.

Products of Problem Formulation

Figure 3.2 depicts the essential elements of the formulated problem.

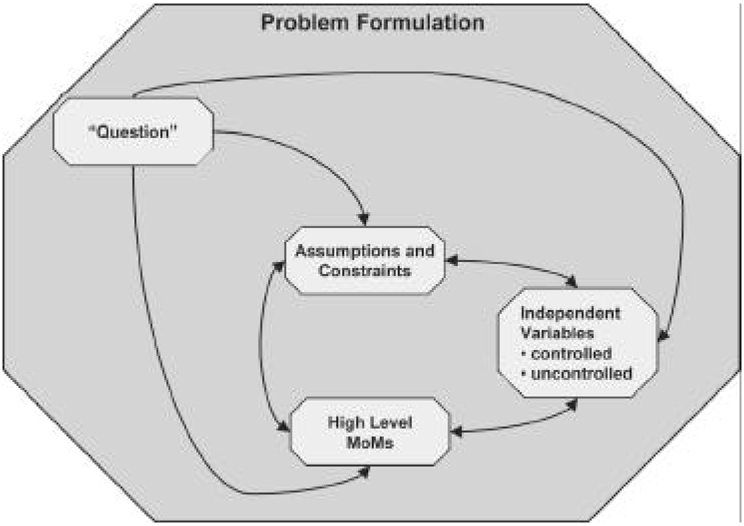


Figure 3.2. Problem Formulation

A checklist can be used to ensure that all the aspects described in the definition have been covered. These include:

- Precise statements of the question being researched;
- A list of independent variables;
- A list of high-level MoM; and
- A list of assumptions and constraints.

Diagrams

Typically, the problem formulation phase should also produce a number of diagrams such as influence maps which summarise the key issues and interactions.

Data Glossary

The problem formulation phase must begin to create a glossary of key data elements, metadata, information, and terms.

Chapter 3 Acronyms

C2 – Command and Control

MoM – Measures of Merit

OOTW – Operations Other Than War

TTP – Tactics, Techniques, and Procedures

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The following additional documents are under development:

NATO C3 System Baseline Architecture

NATO C3 System Overarching Architecture

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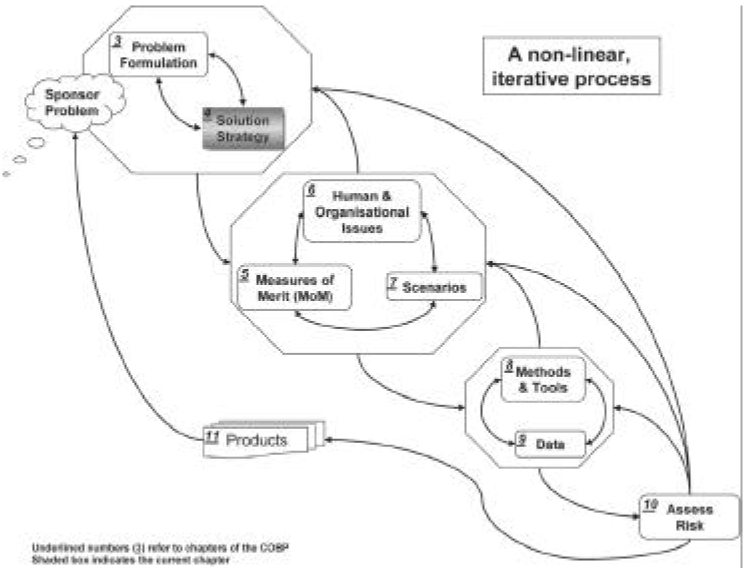
[1]Broad C2 issues include key systems, doctrine, Tactics, Techniques, and Procedures (TTP), organisational structures, and key assumptions (e.g., system performance parameters).

[2]The structured analysis of benefits is a logical process that seeks causally to map lower level MoM that can be related to investments or other actions to higher level MoM that can be valued directly by decisionmakers.

CHAPTER 4

Solution Strategies



Operations research is a scientific method. Executives have often in the past used some of the techniques…to help themselves arrive at decisions…But the term "scientific methods" implies more than sporadic application and occasional use of a certain methodology; it implies recognized and organized activity amenable to application to a variety of problems and capable of being taught.

—Philip M. Morse and George E Kimball,
Methods of Operations Research

The Study Plan

A conscientious effort is required to create and follow a study plan that guides data collection and analyses and prepares for the use of the insights and data to be collected to contribute to a solution to the problem at hand. The study plan consists of two interrelated parts—the formulated problem (*the What*) and the solution strategy (*the How*). The output of the initial problem formulation provides the assessment team with an operating definition of what needs to be done. The output of the solution strategy phase provides the team with an operating definition of how this will be accomplished. As the project unfolds, there will usually be a significant amount of iteration that modifies both the problem formulation and the solution strategy. Without a study plan, it is unlikely that needed efforts will be properly scoped, prioritised, scheduled, and resourced. *Even if the way ahead seems clear, the articulation of a formal Solution Strategy is necessary*.

The objective of this phase of the study is to develop a feasible approach to go from the specification of what is to be done to how it is to be done. This involves developing an approach that will result in the team's ability to collect the data necessary to determine the values of the Measures of Merit (MoM) for specified values of independent variables. The characteristics of data collection instruments and analysis tools and techniques will determine the resources required, the time needed, and the risks inherent in the solution approach. When compared to the study constraints and the problem formulation, it will be determined whether the solution approach is both feasible and satisfies the requirements of the problem formulation (e.g., measures the right things). Figure 4.1 depicts what is involved in moving from a problem formulation to a solution strategy.

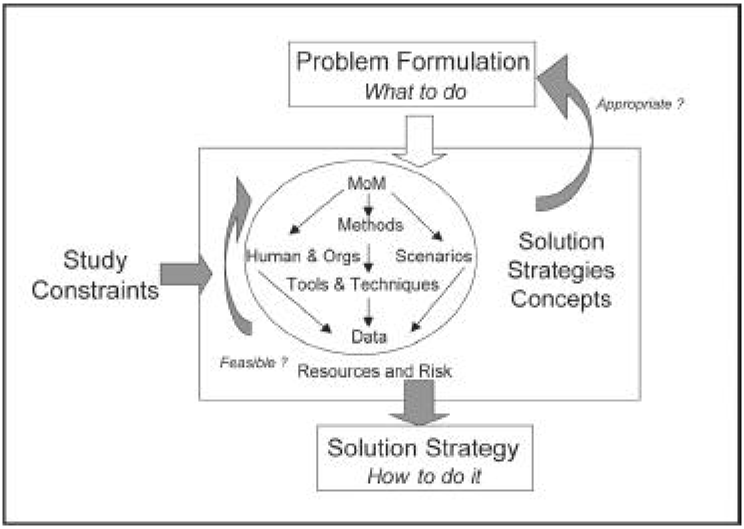


Figure 4.1. From Problem Formulation to Solution Strategy

Key Definitions

Solution Strategy

A solution strategy consists of the specification of a set of sequential and parallel analytical steps, often involving several methodologies and tools. The solution strategy is designed to begin with what is known, and by execution of the specified steps, leads to what one desires to know—an illumination of the issues. The strategy can be:

- simple—calculate mortgage payments by finding the input values for the payment equation and then evaluating the result;

- moderately complicated—define input variables, output variables and precision requirements, create a designed experiment and run the experiment with appropriate measurements including the regression analysis; or
- extremely complex—identify the relevant variables and systems of variables, specify how they might be measured, hypothesize how they are related, and design research strategies that allow for complex adaptive systems or other "messy" structures or processes.

The solution strategy must take the outputs from problem formulation, refine and operationalise them, and develop a plan to collect and analyse appropriate data (including the development and/or selection of models, the design of collection instruments, and the selection of analysis tools) to understand the relationships among the relevant variables associated with MoM, the scenarios, and human and organisational factors. (Figure 4.2)

Measures of Merit (MoM)

MoM are a set of variables that focus the assessment on the issues of interest. In most analyses, these are the dependent variables. In many cases there are significant inter-relationships among the MoM.

Human Factors

Human factors consists of a set of variables that characterise concepts including beliefs, cultural norms, stress, fatigue, fear, arousal, morale, intelligence, and level of experience. In Command and Control (C2) assessments these are typically independent or intervening variables.

Organisational Factors

Organisational factors consist of a set of variables that characterise organisations, such as cohesion, command structure, explicit and tacit relationships, information flows, and organisational cultures. These are also typically independent of intervening variables in C2 analyses.

Scenarios

Scenarios consist of the evolution in time of several elements: a context (e.g., a characterisation of a geopolitical situation), the participants (e.g., intentions, capabilities of blue, red, others), and the environment (e.g., natural, weather and manmade, mines). In C2 assessments, the purpose of scenarios is to ensure that the analysis is performed within the appropriate range of opportunities to observe the relevant variables and their interrelationships.

Model

A model is a physical, analogue, or symbolic representation of relevant aspects of reality for a purpose. It is an abstraction of reality. A model emphasises particular aspects (a subset) of reality.

The assessment model of primary interest is the assessment team's model (conceptual or in some analytic manifestation) of the C2 problem including the variables of interest, their hypothesised relationships, and any prior assumption about their values and linkages. The assessment team may also employ or develop other models or simulations in order to perform analysis or explore risks and uncertainties. Some teams will employ more than one of these analytic tools.

Tool

A tool facilitates the exploration of relationships among model variables and/or develops “solutions” (e.g., maximise value subject to constraints). A tool may be as simple as a checklist or an algorithm, or it may be an extremely large simulation. A simulation is the instantiation of a model that serves to facilitate the exploration of the relationships among the variables – it generates data for analysis and generally emphasises the passage of time. Models and simulations are frequently subdivided into categories of constructive, virtual, and live.

Occasionally, the distinctions among a tool, model, and data are subtle. For example, in a linear program the model is the set of formulas that specify the objective function and the constraints. The tool is the simplex method (or similar algorithmic solution method). The data is an instantiation of the formulas (provides values for the coefficients and constants). In the case of a simulation, the simulation environment and simulation engine are the tools, the coded simulation embodies the model, and the input values to the simulation comprise the data. Often, the simulation code and the data, together, are required for a complete definition of the model.

Data

Data are the values associated with the variables. Data may be ratio, interval, ordinal, or nominal in scale. Data may originate from empirical observation; be derived from models, simulations, or analyses; be established from subject matter experts; or be established by assumption.

Developing a Solution Strategy

The development of a solution strategy is an iterative process that strikes an artful balance between what the team would like to do and what, given the state of the art, the available data, tools, schedule, and resources, is possible to do.

Prerequisites

The solution strategy should not be designed before the problem formulation process is substantially complete (Figure 4.1) and the problem formulation products specified in Chapter 3 are available to the team. This means that:

- The “real” question to be answered is known;
- The assumptions have been articulated;
- The high level MoM have been identified;
- The independent variables have been identified; and
- The constraints associated with the variables have been identified.

However, the assessment team should always remember the inherently iterative nature of the process. Adjustments may prove necessary in the problem formulation as the solution strategy matures.

Steps in Developing a Solution Strategy

As an initial step, the team should elaborate on the MoM to specify the detailed MoM that are to be evaluated. This is sometimes referred to as developing operational definitions for the MoM—definitions that specify the metric to be used, the instrument, and the context in which the measurement is to take place. Often the value of a particular MoM can not easily be observed or measured and one or more surrogate measures are used in its place. In any event, the development of the set of MoM to be used in the study anchors the process that will eventually lead to a solution strategy.

This process (Figure 4.2) revolves around the conceptual model that the assessment team builds, and is at the heart of that process. It is best practise to make this model explicit and have it serve as the common picture that develops a high quality of shared understanding among the team, sponsors, stakeholders, and other key study participants. The initial conceptual model consists simply of the MoM, a first cut of the hypothesised relationships among them, assumptions about variables and their relationships, and constraints. Later iterations include additional independent variables that are known or assumed to affect the values of the MoM or the nature of the relationship among them, increasingly detailed specifications of relationships, and specific values or ranges for the independent variables.

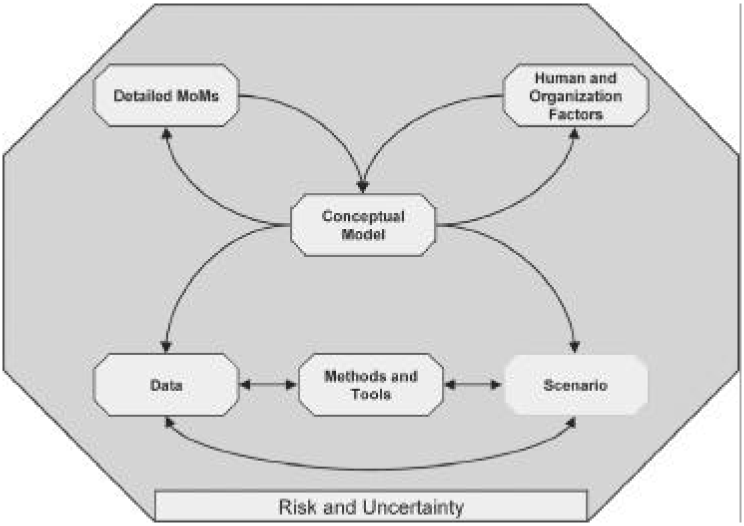


Figure 4.2. Solution Strategy

The identification of human and organisational factors that impact model variables and relationships serves to flesh out the basic conceptual model generated in the problem formulation phase.

Scenarios then need to be derived to provide opportunities in an appropriate context for data collection and exploration of the variables and relationships contained in the conceptual model. The data the study requires are, in large measure, a derivative of the scenarios utilized and the design of the assessment.

The design of an assessment also requires specification of methods and tools and how they will be employed. Methods and tools are required to explore the relationships among the independent variables and between the independent and dependent variables. Complex solution strategies may be necessary. In these cases, multiple analyses will be implied. The problem must be divided into parts, each part requiring analysis with its own set of tools. Frequently the tools that are available do not provide interfaces from one part of the analysis to the next.

Taken together, the detailed specification of the MoM, the development of a conceptual model including the relevant human and organisational factors, the specification of a set of scenarios, and a data collection and analysis plan (that consists of the methods and tools to be used) constitute a solution strategy.

The solution strategy developed needs to be tested to see if it can be expected to address the issues at hand, within schedule and resource constraints, and with accepted levels of uncertainty and risk. However, uncertainty and risks are being continually assessed throughout the process of developing a solution strategy. The team should also consider the form of study output and its relevance to the decisionmaker. Iteration of these ideas with the stakeholders throughout the study helps to avoid surprises and to ensure that the basic assumptions underlying the study have not changed.

Iterating the Study Plan

Figure 4.3 depicts the iterative nature of the process involved in developing the Overall Study Plan, linking problem formulation and solution strategies together with the inputs from study sponsors and stakeholders.

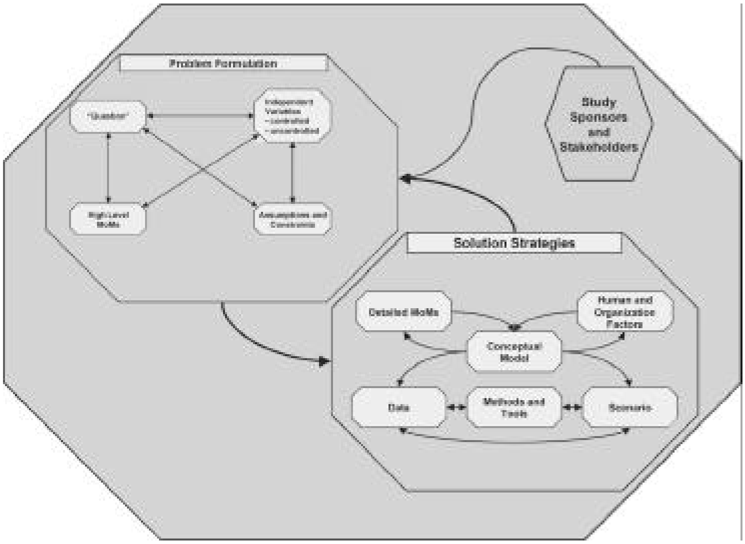


Figure 4.3. Overall Study Plan

A first order feedback loop is shown between problem formulation and solution strategy, with both processes having iterative internal processes. An analysis of the study of risk and uncertainty provides the control mechanism that drives the iterative process to an acceptable result.

Study Management Plan

The team should also create and maintain a Study Management Plan (SMP) to guide the direction, management and co-ordination of the project team. The SMP should include a detailed, time-phased execution plan for the study and a Work Breakdown Structure (WBS).[1] The SMP should show the requirements for all the team products and their delivery dates thereby creating delivery milestones for the execution of the study. It should show the planned dates for all scheduled meetings including progress meetings and technical interchange meetings. The plan should also include a time-phased manning plan identifying the types, quantities, and period of performance for all members of the study team. The SMP should include details of the controls that will be applied to supervise any contractor performance. The team should maintain a current version of the SMP during the study period of performance. The SMP would typically include the associated supporting plans:

- Study glossary;
- Analysis plan;
- Tool deployment and modelling and simulation plan;
- Data collection/engineering plan;
- Configuration management plan;
- Explicit consideration of risk and uncertainty;
- Quality assurance plan;
- Security plan;
- Review plan; and
- Plan of deliverables.

The elements of an ideal SMP are defined and discussed below.

Study Glossary

The assessment team should create and maintain a study glossary comprising all relevant definitions needed in the study. It should aim to create a general study glossary that is improved by every study that uses this glossary. As a starting point, the NATO AAP-6, “NATO Glossary of Terms and Definitions,” or the Joint Publication 1-02, “DOD Dictionary of Military and Associated Terms,” should be used.

Analysis Plan

The assessment team should also create and maintain an analysis plan for the study. The analysis plan should describe the analyses in detail. This description should include the analysis methodology, the tools to be used for analysis, the input data requirements, the Essential Elements of Analysis (EEA), the MoM to be used to evaluate the results, and any analysis assumptions.

Tool Deployment and Modelling and Simulation Plan

The team may create and maintain a tool deployment and modelling and simulation plan covering the needs of each task for numerical simulations or other applied means of operations analysis (OA). It should describe the use of tools and models and simulations in the feasibility study (FS). The plan should include a description of each tool to be used, a list of the key assumptions and caveats for each tool, an analysis of the suitability of each tool in addressing the functionality and performance issues in the FS, the source of input data for each tool, the available output from each tool, and should detail any changes to these tools that are intended. The plan should indicate how data traceability from one tool to another will be maintained.

The modelling and simulation plan may be included as part of the analysis plan in simple studies.

Data Collection/Engineering Plan

The team should create and maintain a Data Collection/Engineering Plan (DCEP) which covers data and metadata necessary to describe:

- The scenario;
- The essential elements of analysis in the analysis plan;
- The MoM to be used to evaluate the result (also in the analysis plan); and
- The input and output parameters of tools to be used within the study.

The DCEP describes and documents who owns the data, where the data can be found (including open sources like the Web), necessary methodologies and procedures to prepare the data, and assumptions and constraints connected to generated data, etc. The data definitions used in the DCEP have to be harmonised with the study glossary.

Configuration Management Plan

The team should create and maintain a configuration management plan. The plan should ensure identification, traceability and control of the descriptions of the system elements, interfaces and architectures considered in the FS, as well as associated documentation. The plan should show how the study database must be controlled and updated. The plan should follow NATO STANAG 4159, “NATO Materiel

Configuration Management Policy and Procedures for Multi-National Joint Projects" (1992), as a guideline. The plan should also ensure that the description of the system configuration being simulated or analysed can be precisely identified, as well as any system or technology improvements considered, with respect to an identified baseline configuration.

Study Risk Register

The team should also identify and assess the technical and schedule risks concerned with the successful completion of the FS. The list of risks identified should be maintained in a study risk register, which shows the probability of occurrence of each risk and its impact on the FS. The register should include the risk mitigation activity for each risk and the expected improvements to time and performance. The study risk register should be regularly maintained, should be available to the assessment team by arrangement, and should be presented at each progress meeting. The Generic Risk Register (GRR) developed during the SAS-026 efforts (Chapter 10) is recommended.

Quality Assurance Plan

The team should create and maintain a quality assurance plan. The plan should declare all relevant quality standards and procedures that are to be applied in the course of the study, and should describe the quality organisation to be used, including the principal quality officers and their lines of authority. The policy and requirements for quality assurance in NATO are given in the following documents, which should be used as guidelines:

- STANAG 4107, “Mutual Acceptance of Government Quality Assurance and Usage of the Allied Quality Assurance Publications (AQAPs),” 6th Edition (March 1998).
- AQAP 100, “General Guidance on NATO Quality Assurance,” 2nd Edition (March 1995) or equivalent/comparable national standards.

The Security Plan

The team should create and maintain a security plan. This plan should contain the approach to the utilisation, storage, publication, dissemination, and control of classified and unclassified materials.

Review Plan

The team should create and maintain a review plan. For every critical phase of the study, preferably marked by respective milestones, reviews of the study have to be planned and executed. Participants should go beyond the members of the study team to include peer reviews. The review results should be documented.

Plan of Deliverables

The team should also create and maintain a plan of deliverables for each phase of the study. This includes what is to be delivered, when it is to be delivered, to whom, in what form and format, and how many copies.

Chapter 4 Acronyms

C2 – Command and Control

DCEP – Data Collection/Engineering Plan

EEA – Essential Elements of Analysis

FS – Feasibility Study

GRR – Generic Risk Register

MoM – Measures of Merit

OA – Operations Analysis

SMP – Study Management Plan

WBS – Work Breakdown Structure

Chapter 4 References

With most textbooks, the bulk of the text is concerned with teaching about the available tools, not with how to use them as an ensemble. Each of the following references provides some information concerning solution strategies.

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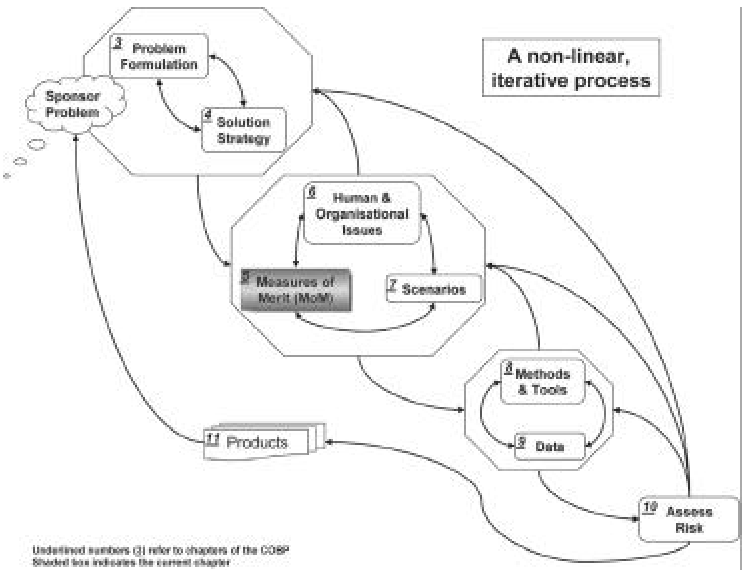
[1]A WBS is a decomposition of the effort into its constituent parts (or tasks) and the assignment of assets to the component tasks. Assets may be people's time, facilities, or other elements required to complete the task. WBS are common in construction and engineering projects.

CHAPTER 5

Measures of Merit



It's best to know what you are looking for, before you look for it.

—Winnie the Pooh, from A. A. Milne

In order to understand the impact of Command and Control (C2), it is necessary not only to analyse and measure the effect of C2 on military operations, but also the effects on the components of the constituent systems. No single measure or methodology exists that satisfactorily assesses the overall effectiveness of C2. Therefore, a multi-faceted and sometimes multi-phased approach is necessary. The benefits of C2 should be evaluated through their impact on the fulfilment of the military and policy objectives, and the impact of C2 should be measured in terms of specific qualities that are relevant to these objectives. A set of scenarios provides the contexts in which Measures of Merit (MoM) are determined.

MoM Challenges

During the last two decades, many new automated C2 systems have been developed and fielded. However, the determination of both the performance and the effectiveness of these systems has proven to be a complex problem. Recognising this, the Military Operations Research Society (MORS) has sponsored several workshops on MoM since 1985. The workshops have led to the development of an analysis framework, Modular Command and Control Evaluation Structure (MCES), for the measurement of performance and effectiveness within a conceptual model for C2. Based on the MORS workshops, the US Army's Training & Doctrine Command Analysis Center (TRAC) developed the C2 Measures of Effectiveness (MoE) Handbook in 1990. This document and the measurement tools developed for the Headquarters Effectiveness Assessment System (HEAT) and the Army Command and Control Evaluation System (ACCES) represented the then established best practices.

The AC/243 Panel 7 Ad Hoc Working Group (AHWG) on the Impact of Command, Control, Communications & Intelligence (C3I) on the Battlefield acknowledged that the specification of measures of effectiveness is difficult. The 1992 final report recommended that a hierarchy of measures be established as an important step in understanding overall system effectiveness, and that systems be analysed at different levels of detail. The types of measures were grouped relating to C2 system performance, force/commander effectiveness, and battle outcome. To quote from the final report, “Measures…are often inadequate and too model or scenario specific. In addition, they have often been generated in ad hoc ways, suggesting a lack of formal analysis in their development.” Since then, RSG-19, SAS-002 and SAS-026 have canvassed the field, and have brought together the best ideas and practices in order to support MoM development and applications within C2 assessment.[1] This version of the Code of Best Practise (COBP) extends this thinking and includes the Operations Other Than War (OOTW) domain.

Definitions

It has been recognised that a single definition for measures of performance (MoP) and effectiveness (MoE) does not exist. MoM is recommended as a generic term to encompass different classes of measures. The measures are defined in hierarchical levels related to each other, each in terms of its own boundary. From the conceptual viewpoint, it is important to keep in mind the level of analysis and the context in which the measurements are made.

Within the MCES framework, MORS has developed a four-level hierarchy of measures from high-level force effectiveness to low-level rudimentary measures of physical entities, which were adopted by RSG-19. In the context of OOTW, a fifth level is added, Measures of Policy Effectiveness (MoPE), to characterise the contribution of military actions to broader policy and societal outcomes. For OOTW, political factors are paramount and considerations such as media coverage, local regional stability, and sustainment of community societal standards must be taken into account. Military missions may not directly achieve policy objectives, although they often strive to provide an environment more conducive to these objectives. However, MoE of military tasks should quantify performance against military missions, not the overall political aspirations.

The Code of Best Practice has adopted the following five levels of MoM:

- Measures of Policy Effectiveness (MoPE), which focus on policy and societal outcomes;
- Measures of Force Effectiveness (MoFE), which focus on how a force performs its mission or the degree to which it meets its objectives;
- Measures of C2 Effectiveness (MoCE), which focus on the impact of C2 systems within the operational context;
- Measures of Performance (MoP), which focus on internal system structure, characteristics and behaviour; and
- Dimensional Parameters (DP), which focus on the properties or characteristics inherent in the physical C2 systems.

Figure 5.1 emphasises the diminishing impact of a particular MoM as the circle widens.

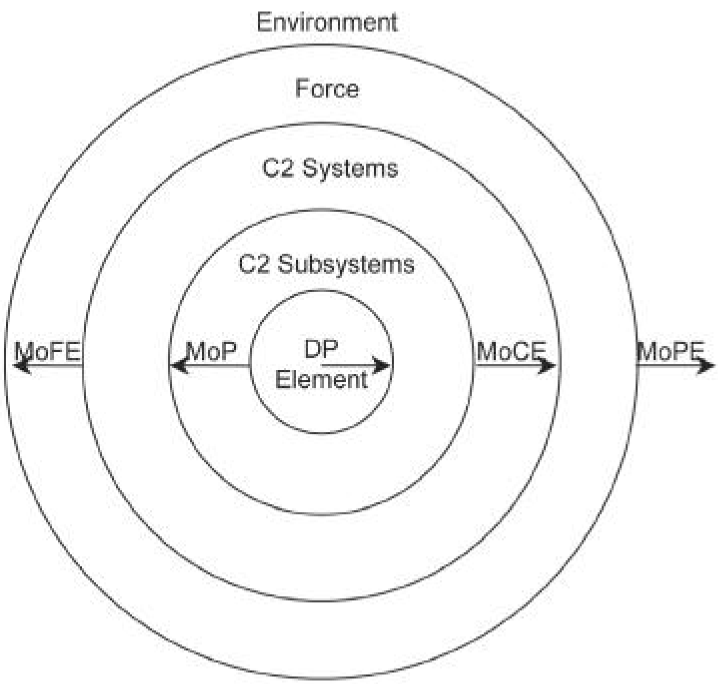


Figure 5.1. Relationships of Measures of Merit

Measurement Objectives

The important issues raised by decision-makers require a sense of the degree to which C2 performance may improve force and policy effectiveness. Therefore, C2 assessments are often called upon to provide convincing evidence of the expected improvements in mission effectiveness that can be attributed to improved C2. The ideal approach may be to define a single measure that reflects the military and political objectives of the missions under consideration. However, the determination of such a measure is generally not feasible, although not necessarily impossible for particular classes. In most decisionmaking problems, it is necessary to define several measures that together provide the necessary insights. A major reason for this is that a single measure may not provide sufficient scope and/or detail to analyse the impact of specific C2 elements, particularly second and third order effects or unintended consequences. Many analyses are conducted precisely in order to enable trade-off between important equities which can only be seen if a set of MoM is generated for analysis. The set of MoM selected must be comprehensive to ensure that all factors are considered.

MoM are used to compare different options on equal terms, and serve a wide range of purposes, including:

- Establishing a standard or expectation of performance (for new requirements);
- Establishing the bounds of performance of a system as well as the effects of imposed constraints;
- Comparing and selecting alternative systems that may be very dissimilar but are designed to achieve a similar purpose;
- Assessing the utilisation of a system in new or unexpected application domains or missions;
- Identifying potential weaknesses in specific areas of an organisation or system (areas of high error potential or high user workload);
- Analysing the impacts of organisational changes;
- Analysing training effectiveness;

- Determining the most cost-effective approaches to achieve desired objectives;
- Comparing a replacement system, or components of a system, against predecessors or competitors;
- Assisting in generating and validating requirements and deriving specific C2 requirements from broad statements of objectives;
- Evaluating the effectiveness of human decisionmaking in the C2 cycle;
- Determining the degree of mission success; and
- Determining the return to normality in OOTW.

Characteristics of MoM

The development of an operational definition of the measure, the development of instruments, the application of the instruments to collect of appropriate data, and the establishment of relationships among a group of MoM vary in difficulty, effort, cost, precision, generalizability and other characteristics. These differences are often related to the type(s) of MoM involved and the domain in which the measurement needs to take place.

C2 Assessments involve measurement of variables that exist in the physical, information, and cognitive domains.[2] In general, the development of operational definitions, instrumentation and data collection for variables to be measured in the physical and information domains are more straightforward and require less effort and expense than dealing with variables that are measured in the cognitive domain. Furthermore, the former can be measured more "precisely," are easier to comprehend, and are less subject to interpretation than the latter.

In general, DP, MoP related to systems, and MoFE tend to be measured in the physical domain (e.g., bandwidth, computing capacities, time to accomplish a task, force exchange ratios) while MoP related to measures of C2 effectiveness (quality of awareness, shared awareness, and trust) and MoPF (will of an adversary, public opinion) tend to be measured in the cognitive domain.

As one goes up the hierarchy of MoM, the measures tend to become more context, task, or mission specific. For example, the performance characteristics of systems (DP) apply to systems in general but MoFE are usually limited to a set of tasks or missions. MoFE for combat are very different from MoFE for various OOTW. If done well measures of C2 effectiveness will be scenario independent so one can compare C2 effectiveness across a range of missions and circumstances.

Except for DP any of the MoM can be either an independent or dependant variable in a given assessment with any of the independent variables being either "controllable" or not. The difficulty in establishing relationships among the MoM varies as a function of the level of the independent variable.

The Assessment Team should recognize and plan for the difficulties associated with using various MoM and should avoid substituting easier to deal with but less relevant MoM. It is always better to try to measure (estimate, approximate) MoM that reflect first order effects than to precisely measure MoM that do not adequately reflect key aspects of the problem.

Measuring MoM

This section outlines measurement theory concepts that apply to ensure that the right measuring instruments are selected and applied correctly. By definition, measurement is the assignment of values to observation units that express properties of the units. Four levels of measures relate numbers to properties of interest: nominal (e.g., artillery vs. infantry), rank or ordinal (e.g., worst to best), relative or interval value (e.g., change in temperature), and absolute value or ratio (e.g., 2 kilobits per second). Analysts must ensure that the specific MoM adopted are at the appropriate levels of measurement.

The key properties for quality assurance are reliability and validity. Other significant properties include practical issues, such as the effort required to collect appropriate data and the convenience of measurement (e.g., whether the collection process itself interferes with the conduct of an exercise or experiment). Ideally, measurements should be easy to capture and easy to apply. There are clearly trade-offs to be made between MoM that may closely track the property of interest and that are costly and/or difficult to measure and those that are less strongly related to the property of interest but that are easier to measure. The effort required for collection bears no direct relationship with validity, but reliability may be related to cost. Reliable measurements require repeated observations and appropriate sample sizes. Reliability represents accuracy and consistency. A cost-effective measurement plan provides enough data for useful and definitive conclusions. However, cost and/or convenience of measurement may be an overriding factor in system evaluation.

Failure to take validity and reliability into account raises the risk of generating false conclusions. Validity and reliability are not absolutes, but matters of degree. Validity is the degree to which a measure characterises the attribute of interest and only that attribute. Complex concepts often require multiple measures to provide valid information. In order to make a valid link between the performance of a system as a whole against performance of its components, the measures must correspond to critical tasks. Reliability represents accuracy and repeatability. A measure may be reliable but not valid, or it may be valid but not reliable.

Validity

The properties of validity may be categorised into five types: internal, construct, statistical, external, and expert.

- Internal validity is defined as the establishment of causal relationships between variables of interest. This is necessary to accept a hypothesis that a given measure is responsible for a specific effect on another measure;

- Construct (also referred to as content) validity means that the target objects, and only the target objects, are measured;

- Statistical validity implies that sufficient sensitivity is involved in order to determine relationships between independent and dependent variables.

Statistical tests control two types of errors in measurement. Type I, or alpha, is the probability of rejecting a claimed hypothesis that is true, Type II, or beta, is the probability of accepting an hypothesis that is not true;

- External validity implies that the results may be extended to other populations or environments; and
- Expert validity refers to the degree to which measures are accepted by those knowledgeable in the field.

A MoM should meet the validity-related criteria outlined in Table 5.1.

Validity Criterion	Definition
Mission Oriented	Relates to force/system mission
Realistic	Relates realistically to the C2 system and associated uncertainties
Appropriate	Relates to acceptable standards and analysis objectives
Inclusive	Reflects those standards required by the analysis objectives
Discriminatory	Able to distinguish measurement parameters
Meaningful	Accepted by subject matter experts
Simple	Easily understood by users
Relevant	Target objects, and only the target objects, are measured
Generalisable	Extent to which results may be extended to other populations or environments

Table 5.1. Validity Criteria of Measures

Reliability

Reliability involves the expectation of errors associated with measurements. It is defined as the accuracy of a measurement, as reflected in the variance of repeated measurements of the same phenomenon. The key principles of reliability are consistency (repeatability) and accuracy. The variance associated with measurement must be known or estimated to interpret results and to discriminate between real effects and measurement effects.

The reliability-related criteria that MoM should meet are outlined in Table 5.2. Additional criteria that have proven usual in the past are outlined in Table 5.3.

Reliability Criterion	Definition
Discriminatory	Identifies real differences between alternatives
Measurable/Observable	Available for measurement
Quantitative	Can be assigned values, numbers, or ranks
Objective	Defined or derived, independent of subjective opinion
Sensitive	Able to ascertain changes in system variables
Consistent	Same results are obtained on repetition

Table 5.2. Reliability Criteria of Measures

Criterion	Definition
Timeliness	Sampling rate adequate to detect changes
Adaptability	Sufficient within available resources
Flexibility	Capability across a range of anticipated situations
Robustness	Capability across a range of unanticipated situations

Table 5.3. Other Useful Criteria

Practical MoM Issues

The assessment of C2 requires the application of a framework to yield values for appropriate MoM. Analyses of C2 systems and processes often reveal a complex hierarchical composition. A structured resolution/functional decomposition approach may be related to the organisational structure to yield performance measures for the organisation as a whole, individual components within the organisation, and specific tasks within the organisational cells.

If the analyst assumes that C2 effectiveness is positively correlated with overall military unit effectiveness, MoM could be obtained by addressing the outcomes or products of such unit activities. Goal-level evaluation attempts to define the ability of the specific military formation to make the system state match the goal (directive) provided by the superior headquarters. These are measures of force effectiveness. The degree to which the system state matches the desired goal states indicates a level of effectiveness. Alternatively, C2 effectiveness may be viewed as dependent on the functional processes of the C2 system, with measures obtained mainly at the task level.

A C2 assessment framework encompasses several factors that must be considered iteratively, as discussed in the introductory chapter. Typical factors important for the identification and selection of MoM include the:

- Assessment configuration, e.g., storyboard, testbed, constructive simulation, field trial;
- Assessment goal or purpose;
- Context, assumptions, and constraints;
- Scenarios or stimuli;
- Collection means, e.g., subject matter experts, automatic data logging;
- Analysis plan; and
- Interpretation of results.

Categories of Measures

A common thread in the approaches for C2 assessment is the functional decomposition of the C2 cycle. C2 effectiveness depends upon the functional processes of the C2 system, and the evaluation of functions may be determined by data measured at the task level.

The evaluation of tasks provides the most detailed insight into C2 activities. The primary measures are expressed in terms of time consumed and accuracy. Task analysis must be performed prior to evaluation, with the identification of task definition and the critical elements for successful task completion.

Measures of a C2 system's behaviour may thus be reduced to measures based on time, accuracy, or a combination which may be interdependent. Time based measures are quantitative, while accuracy measures may be quantitative or qualitative.

For C2 tasks, time-based metrics include the:

- Time taken to react to an event (time to notice process and act upon new information);
- Time to perform a task (time to make decision);
- Time horizon for future for predictive analysis; and
- Rate of performing tasks (tempo).

Metrics for accuracy include:

- Precision of the observed system(s) performance;
- Reliability of the observed system(s) performance;
- Completeness (known unknowns, unknown unknowns);
- Errors (alpha, beta, omission, transposition, severity); and
- Quality of information produced.

Some accuracy measures may be calculated in units of time, e.g., the time taken to detect an error. Quality of decisions is difficult to evaluate objectively, except by focusing on outcomes. The processes involved may have to be examined to obtain objective measures, or subject matter experts may be consulted to make an evaluation. Accuracy of information implies both the accuracy of the data and the accuracy of the interpretation of the data.

Time based and accuracy measures often bear an inverse relationship, implying a trade-off between speed of performance and accuracy of performance. Speed of performance must be specified in terms of minimum desired accuracy or completeness, and accuracy measurements in terms of time available. Therefore, the specification of thresholds or standards for metrics must be referenced in terms of imposed constraints.

Examples of time and accuracy based measures are compiled in Table 5.4. Table 5.5 provides some additional examples, specifically MoP and MoCE.

Measure	Example
Time-Based	
Time to perform fixed or sequence of tasks	Planning tasks
Time to perform a variable task	Developing and selecting options or courses of action
Time to recognise or respond to an event	Response to a critical enemy contact
Time to achieve a target state	Tactical objective
Percentage of time on target	Data bases up to date
Number of events in queue	Messages pending action
Timeliness of responses	Fire plan schedule
Accuracy-Based	
Accuracy or precision of performance of tasks	Information on maps, data bases
Sensitivity of detecting system events	Recognition of events requiring change in plans
Probability of making errors	Errors in fire plan target schedules
Time to recognise existence of error	Necessity for plan alteration
Time to recover from error	Time to redo part of plan
Knowledge of current system status	Comprehension of battle situation
Quality of decisionmaking	Quality of tactical plan

Table 5.4. Examples of Time- and Accuracy-Based Measures

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

Table 5.5. Examples of MoPs and MoCEs

Example Headquarters C2 MoM

C2 measures may also be divided into sets corresponding to the sequential steps of the C2 cycle. These include:

- Monitoring and understanding: information transmission, values, times, effect, comprehension;
- Planning: information exchange, coordination, impact, flexibility, process quality; and
- Directing and disseminating.

The MoM for C2 can also be focused on four levels: a network of headquarters, a single headquarters, the individual cells within the headquarters, and performance of specific tasks within the cells.

OOTW MoM

While national NATO policies require that military forces be prepared for high intensity conflict, forces have been increasingly involved in low-intensity conflicts and C2 analyses for OOTW are therefore becoming important. OOTW include force deployment to create or maintain conditions for a political solution in order to avoid escalation into hostilities. Threats to international and national security may also unfold from natural disasters, terrorism organised crime, civil unrest, migration, or other territorial intrusions. Most OOTW are inherently joint or combined operations.

While the determination of MoM has been stated as difficult to obtain, OOTW offer even greater challenge for MoM. Traditional MoFE such as loss exchange ratios, combat effectiveness, or duration of the campaign are rarely applicable to OOTW. In such operations, military forces may play important roles but political concerns may limit the scope of imposable solutions. Public and political pressures may result in shifts in the selection of criteria for MoM e.g., more emphasis may be placed on personnel casualties and less on equipment losses.

OOTW MoPE

While MoFE and MoCE provide measures of success for military operations, MoPE measure the degree of attaining political objectives. In some cases, such as humanitarian assistance or nation building MoPE may measure the degree of improvement in the quality of life of the populace.

MoFE usually were the highest MoM used within the analysis of Article V missions[3] assuming that effectiveness is directly related to the higher level MOPE such as “winning the war.” However, such an assumption may not always apply to OOTW. For example, military actions that would be highly effective in accomplishing mission objectives in war might be quite counterproductive in OOTW. In fact, the value of military actions in OOTW is not so much a question of physical effects, but rather how military actions and their physical effects are perceived by the various actors and the population in the theatre, how the military actors interpret the behaviour of the other actors and the critical mission task conditions such as, for example, political interest and media attention.

McCafferty and Lea developed low-level military-related measures (MoCE) to cover OOTW (McCafferty and Lea, 1997). The MoM, which are classified as MoCE, include the:

- Time between the arrival of friendly forces in the area and their deployment;
- Time between deployment of friendly forces and contact with adversary forces;
- Length of time adversary forces were under observation without posing a threat to friendly forces;
- Length of time friendly forces are in potential danger (i.e., adversary forces have the opportunity to fire on friendly forces); and
- Time horizon of friendly C2 processes (how far into the future they are focused).

Mobility may be important for OOTW, as well as sustainability and self-sufficiency in theatre, with the implication of emphasising measures of reliability and maintainability. Moreover, the perception of the capabilities of deployed forces acts as deterrence or coercion on the parties in conflict.

Some examples identified by McCafferty and Lea are:

- Opportunities to employ forces, which reflects the range of military capabilities available;
- Strategic deployment, which is related to deploying and recovering the right force to theatre efficiently and in time;
- Endurance, to maintain an effective force in theatre for an extended time;
- Mission objectives, to measure the success of achieving military objectives in OOTW; and
- Successful termination, to deal with progress to the desired end state (the criteria may be political and thus not measured by military activities).

One class of effectiveness indicators in OOTW is provided by transition measures, which focus on the progress in the transfer of responsibilities to the follow-on military force or civil agency. Transition measures focus on the degree that follow-on organisations assume tasks and responsibilities.

Progress toward success may be tracked by normality indicators, which are indirect measures of the effects of military involvement in OOTW, although causal relationships are difficult to prove (Lambert, 2000).

These MoPE may be obtained by evaluating the extent to which conditions have been restored.

Normality indicators measure the level of improvement in the quality of life of the general population, and may be defined as "relative measures of the state of normalcy characterising an element of the civil environment, through data collected on a regular basis and assessed to have the frequency, quantity, consistency and coverage required to make a useful objective assessment of the changes occurring in the civilian populace." (Department of National Defence, Canada, 1999). Normality indicators can be grouped in categories and adapted to meet the changing requirements: political, socio-economic levels of development, cultural, legal and technological.

Criterion	Examples
Political	Elections, political participation
Economic	Unemployment, interest rates, and market baskets
Social	Number of students in schools, number of refugees
Technological	Telephone system availability
Legal	Judicial system functioning
Environmental	Roads, water supply, power supply
Cultural	Sports events, concerts

Table 5.6. Normality Indicators

Limitations of normality indicators include:

- Inexperienced personnel available for data collection and analysis. A mix of inexperienced civil and military personnel are often assigned to collect data in fields foreign to them; training may be necessary to assure reliable and valid data;
- Temporary effect due to military presence for data collection. The mere presence of military personnel collecting data may affect normality measurements;
- Difficulties in obtaining valid and reliable data calibrated against baselines. It may be difficult to

establish the threshold for "normality" if archive data is not available;

- Extrapolation in space and time from a specific locality. It may be inappropriate to extrapolate civil progress to an entire region. Sampling is important;
- Limited resources and constraints for collection and analysis. Data must be collected consistently but may be occasionally unobtainable due to physical inaccessibility or lack of personnel;
- A "snapshot" which may not provide trends if infrequently obtained. Trend analysis requires sufficient data and sampling rates; and
- During OOTWs, the relevant MoM may change over time, particularly the lower level MoCE and MoP. For example, during the earliest phases of NATO operations in Bosnia, tracking weapon systems and knowing how many of them were in cantonments was a major MoM. Once the forces were separated and most weapon systems under control, emphasis shifted to the disruptive activities such as road blocks and ethnic harassment. As these behaviours became less frequent, NATO's emphasis shifted to normality indicators.

MoM Hierarchies: Some Examples

Modular Command and Control Evaluation System

Evaluation of C2 effectiveness requires a comprehensive approach for the preparation of the evaluation process, the collection of data, and its interpretation. MCES addresses both the managerial and analytical aspects of evaluation and was originally developed for the systematic comparison of C2 systems. The objective of MCES is to guide analysts in the identification of appropriate measures for estimating the effects of C2 on combat.

MCES prescribes a process of measurement, but does not identify either a measurement system or a set of measures. Similarly, while calling for the collection of data, MCES does not provide details on how data are to be collected. MCES does provide guidance on how good measures and good collection procedures are characterised, but leave the details of the measurement, data collection, and analysis plans to the analyst.

MCES considers C2 as consisting of three components:

- Physical entities (equipment, software, people);
- Structure (interrelationships of entities); and
- Processes (C2 functions).

The boundary of a C2 system here is defined as a delineation between the system studied and the environment. The US Army's Training and Doctrine Command (TRADOC) C2 MoCE Handbook adds mission objective as the top layer of the hierarchy of C2 components.

MCES focuses on measures as opposed to models, but includes the cybernetic loop model of generic C2. It consists of seven procedural steps.

HEAT

While originally developed for theatre-level combat applications, the HEAT system has proven robust. For example, it has been used to assess US Department of State crisis task force performance, military operations in Grenada, Panama, and Haiti, and several exercises focused on peacekeeping, and humanitarian assistance missions. The underlying C2 process of monitoring, understanding, and developing alternative actions; predicting the consequences of each alternative for each possible future under consideration, decision; developing and promulgation of plans and directives and requests for support; seeking information; making reports; and responding to inquiries are all relevant across the ranges of OOTW missions. HEAT has been modified since 2000 to include measure of the quality of collaboration, which is often a key process in OOTW.

ACCES

ACCES is a derivation of HEAT, which was developed primarily for joint theatre-level operations. ACCES reorganised HEAT concepts into army doctrinal language and doctrine, but shares the same philosophy. ACCES has been applied to numerous division and corps command centre assessments. It represents a comprehensive set of practical and objective performance measures for C2 activities. The primary focus of ACCES is the overall performance of a command centre or network of command centres, at various stages of the C2 process, from the collection of data to the conversion of data to intelligence to the implementation of plans and directives. The underlying approach to ACCES is that C2 comprises interdependent sub-processes which can be observed and measured. ACCES considers C2 as an adaptive control process, where information collected from the outside is processed internally to generate plans that may be adapted to reflect new information. ACCES takes the view that the overall effectiveness of a command centre can be judged by the viability of its plans. A good plan is one that can be executed without the need for modification beyond the contingencies stated in the plan and that remains in effect throughout its intended life.

Multi-Attribute Utility Theory (MAUT)

MAUT is similar to ACCES in the sense that both use functional decomposition and function-specific evaluation metrics. The major differences are that MAUT can be used with any set of metrics (including those from ACCES), which must be specified by the analyst. MAUT assigns weights to the MoM at each level of the MoM hierarchy and utility values or scores at the lowest level. MAUT then aggregates upwards the weighted scores to provide composite scores of effectiveness. MAUT, if properly used with appropriate application of judgmental weights, will allow integrated analyses based on multiple MoM. While this is often satisfying to decisionmakers (it provides a single index of quality), analysis should always monitor the components of such indices as they may provide insight into strength and weaknesses of the C2 system. For example, many OOTW C2 problems involve a variety of objective functions and trade-offs. MAUT results should always be assessed by sensitivity analyses.

Many applications of MAUT assume additive composition of MoM. However, this is a very restrictive assumption that needs to be validated in each case. In addition MoM may interact suggesting that the aggregation of MoM is at partly multiplicative (Keeny and Raiffa, 1976; Sarin, 2000).

Collaboration C2 Metrics

The following collaboration metrics have evolved out of work done by Evidence Based Research, Inc. for the United States Office of Naval Research. These collaboration metrics focus on individual and team cognitive/awareness, team behaviour, and team products. Individual cognitive metrics measure collaboration, team members' understandings about their mission and their team, and team cognitive metrics apply the individual cognitive metrics to quantify the level of awareness in a team. There are four classes of these metrics:

- Averages of the understanding among team members;
- Extent of alignment of these understandings;
- Maximum level of understanding anywhere within the team; and
- Presence of gaps in understanding throughout the entire team.

Team behaviour metrics measure the key behaviours indicative of effective teams. These behaviours include smooth and efficient synchronisation, efficient information exchange, adaptability, effective workload distribution, and team member engagement. Team product metrics measure product quality and team efficiency and are the bottom-line "proof of the pudding" metrics, applicable whether a team or a single individual produces the product.

Other metrics under consideration are: task performance, workload, level of engagement (buy-in), synchronisation, information needs workload and handling, workload awareness and handling, and problem awareness and handling.

Other Considerations in the Selection and Interpretation of MoM

Effects of Uncertainty

In order to state a level of confidence in the interpretation of MoM, the underlying assumptions must be clearly stated and uncertainties recognised. Uncertainties manifest themselves in several ways that may affect MoM. They may be grouped as follows:

- Study assumptions—(uncertainties in the scenario, model input);
    - Relevance to the purpose of the evaluation, uncertainties in the military objective, knowledge of enemy concept of operations, intentions, capabilities, weapon performance, uncertainties in terrain data, etc.
- Modelling assumptions—(uncertainties in the model, structural uncertainty); and
    - Human performance, parameters, objects, attributes, processes, effects of constraints, effects of aggregation and de-aggregation,

deterministic (usually high hierarchical level but low resolution) versus stochastic models, especially in OOTWs; and

  - Uncertainties about the implications of value changes in lower-level MoM with respect to the values of higher-level MoM (e.g., increases in arrest rates at late stages of an OOTW may be negative, while increases in arrest rates at early stages may be positive).

- Model sensitivity—(uncertainties in the outcome)
  - Hypersensitivity to input variations, (instability or chaos theory), effects of model non-linearities and non-monotonic behaviour (effects of thresholds), decisionmaking for local versus global optimisations, etc.; and
  - Sensitivity analysis may be applied to identify uncertainty. By varying the assumptions and input data within the plausible ranges, excursions in the analysis verified by the subject matter experts provide insight into the effects of uncertainty.

Impact of Technological Changes

The rapid pace of technological change involving information systems is causing major changes in the way C2 is perceived and executed, leading to potential changes in the way war fighting commands are organised. For example, the last decade has seen the emergence of collaborative technologies, which enable new ways to command and control military forces and for them to interface with other actors. To keep pace with and to evaluate the impacts of these changes, the nature of these changes and impacts need to be understood so that the appropriate MoM can be developed.

One approach to doing this postulates those differences likely to occur between today's C2 and future C2, and then describes an evaluation methodology, including MoM, to measure the impact of the changes. Other approaches are Social Construction of Technology (SCOT) (Bijker, 1989), Socio-Technical Networks (Elzen, Enserink and Smit, 1996) and Actor Network Theory (ANT) (Latour, 1997).

Conclusions

No single measure or methodology exists that satisfactorily assesses the overall effectiveness of C2 systems. As a minimum, the following factors must be considered in conducting an analysis of C2:

- Determine the appropriate levels of MoM hierarchy;
- Identify specific MoM which are practically obtainable;
- Specify means of collection of MoM;
- Assure the validity and reliability of measures for correct interpretation with quantifiable levels of confidence;
- Be aware that variation in measurements (e.g., due to human factors) may well cause unacceptable levels of uncertainty. Hence the analyst must pay particular attention to measurements related to the human element;
- Consider that while MoPE and MoFE may provide the most persuasive measures from the military

perspective, MoCE and MoP are the most readily derivable by operations analysts; and

- Account for the principles of reliability and validity to avoid the risk of generating false conclusions.

Recommendations for Generation and Selection of MoM

The principal objective for MoM is to determine judgements of the degree to which C2 or changes to C2 may improve force effectiveness and to provide convincing arguments for the improvements. It is important to stress that the purpose is to assess the contributions of C2 in terms of how C2 improves the effectiveness of military missions, and not the quality of the C2 process itself. However, to arrive at these assessments and assign attribution to the C2 system, the C2 system must be included in the analysis. To achieve this objective, the following steps are required:

- The objectives for the assessment must be established and clearly stated;

- Selection of MoM should not be done in isolation from consideration of the assumptions, constraints, models, tools, scenarios, or other elements of the analytic plan and assessment process. The assumptions used in the model and/or evaluation must be stated along with their potential impact on the results;

- A detailed assessment of reliability and validity of the selected measures needs to be made in order to determine a level of confidence in measures; and

- For C2 acquisition analyses, the generation of measures should occur in parallel with the development of the system, so that as the system is being matured, developers can know the standards to which they are being held.

Summary of the Challenges and Issues in the Evaluation of C2

- Correlation of MoPE and MoFE with C2 process measures (e.g., battle outcome against lower-level measures) is difficult;
- Separation and linkage of the respective relationships between C2 and users, organisations and military objectives requires some effort;
- Aggregated measures (e.g., as obtained from ACCES or MAUT) have limitations in the diagnosis of C2 success or failure. A careful analysis is required to provide a comprehensive assessment of highly complex C2 systems based on a small number of summary measures of outcome and process;
- The assessment of the reliability of measures in an environment where sample sizes are small will remain difficult and may require the use of non-parametric statistics;
- The analyst must pay attention to the complex task of establishing and measuring control variables in order to achieve correlation of measures against a wide spectrum of scenarios and staff;

- Defining criteria to differentiate measures must be established;
- Verifying measurement criteria (e.g., discrimination) must be ensured;
- For the near future, collecting data to support C2 measures will remain labour intensive because C2 processes remain human intensive;
- Many of the measures for information processing concern completeness of the information. Deciding what makes information complete requires coordination and cooperation between the assessor and the user;
- The relationship between outcome and process may be complex because C2 is an integrated system with continuous feedback;
- The analysis of uncertainties and measures of central tendency and dispersion are both significant when examining C2 issues; and
- A Command Post Exercise (CPX) is a useful venue for evaluation of C2. However, the costs involved generally preclude conducting a CPX solely to evaluate the C2 process or a C2 system. Cost control is increasingly leading to the use of laboratory and human in the loop experimentation to develop knowledge and insights.

Summary of the Challenges and Issues for OOTW MoM

- Cost/benefit: cost in time and effort for data collection and analysis may outweigh benefit;

- Standardisation of data collection, evaluation, and analysis with many diverse non-governmental organizations (NGOs), UN agencies, and militaries;
- Factors outside military control: other agencies, policy restrictions;
- Creation of a rich and comprehensive set of MoM to preclude reliance on a limited number of MoM as the key to success;
- Availability and consistency of information (e.g., in OOTW, a possible consequence of different factions controlling geographic areas);
- Merging of strategic, operational, and tactical domains; and
- Clear recognition of roles and responsibilities of all participants.

Chapter 5 Acronyms

ACCES – Army Command and Control Evaluation System

AHWG – AC/243 Panel 7 Ad Hoc Working Group

ANT – Actor Network Theory

C2 – Command and Control

C3I – Command, Control, Communications & Intelligence

COBP – Code of Best Practise

CPX – Command Post Exercise

DP – Dimensional Parameters

HEAT – Headquarters Effectiveness Assessment System

MAUT – Multi-Attribute Utility Theory

MCES – Modular Command and Control Evaluation Structure

MoCE – Measures of C2 Effectiveness

MoE – Measures of Effectiveness

MoFE – Measures of Force Effectiveness

MoM – Measures of Merit

MoP – Measures of Performance

MoPE – Measures of Policy Effectiveness

MORS – Military Operations Research Society

NGO – Non-Governmental Organization

OOTW – Operations Other Than War

SCOT – Social Construction of Technology

TRAC – TRADOC Analysis Center

TRADOC – US Army Training & Doctrine Command

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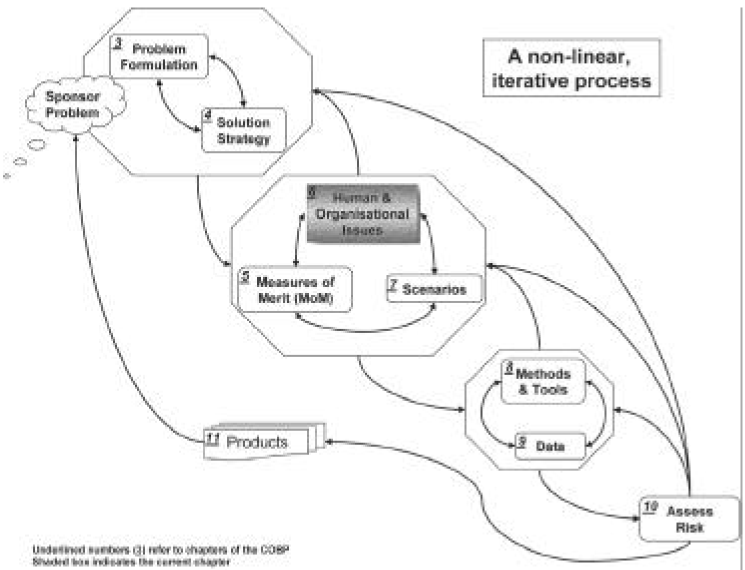
CHAPTER 6

Human Organizational Factors



If I had time…to study, I think that I should concentrate almost entirely on the 'actualities of war,' the effect of tiredness, hunger, fear, lack of sleep, weather…It is the actualities that make war so complicated and so difficult, and are usually neglected by historians.

—Field Marshall Archibald Wavell, 1883–1950,
Author of *Soldiers and Soldiering*

Importance of Human and Organisational Factors

The human dimension largely distinguishes command and control (C2). Key differences between C2 analyses and traditional military operations analysis (OA) applications include the need to deal not only with military organisations, but also with distributed military teams (and organisations) under stress and their decisionmaking behaviour as well. Moreover, in operations other than war (OOTW), consideration must be paid to the behaviour of and interaction with non-military organisations, political groupings, and amorphous groups such as crowds and refugees. Thus, the formulation of the problem and the development of solution strategies cannot be completed without explicit consideration of both human and organisational issues.

The human factors of interest fall into three major categories:

- Human behaviour related to performance degradation, such as stress and fatigue, and as a consequence of social interactions among individuals and members of groups;
- Decisionmaking behaviour (cognitive questions) including the cognitive complexity of the issues and the capacities of the commanders or other decisionmakers of interest; and
- Command style.

By contrast, organisational factors deal with relationships among groups of individuals, including connectivity, roles, and organisational structures.

Since both human and organisational factors can affect C2 performance, the operations analyst must consider their impact early in the research design process and review a priori assumptions about them in an iterative manner throughout the entire analytical process. Human and organisational factors must be considered as part of structuring the problem, selecting measures of merit (MoM), defining scenarios, developing solution strategies, and selection of tools.

The first key consideration when structuring the problem is whether individual decisionmaking and behaviour of individuals or groups is important to the C2 processes under analysis. If the research question can be answered without considering differences between individual decisionmakers and groups then the additional complexity that issue introduces should be avoided. For example, in addressing a C2 issue that deals, all other things being equal, with a simple change in connectivity (which headquarters will have which linkages to others), human behaviour may not be important to the analysis at least as long as combat missions are involved. However, the same change in connectivity might affect relations with non-military organisations and individuals essential for mission success in OOTW suggesting their response must be accounted for in an appropriate manner. Thus, deciding on the importance of human issues in OOTW and identifying the issues at stake requires a good general understanding of human behaviour and its underlying motivations beyond military common sense as well as knowledge about relevant cultural factors and the interests of the parties involved.

Human Factors

Human Performance and Behaviour

Human performance affects behaviour and vice versa. Human performance depends on psycho-physiological variables (e.g., stress, fatigue, sleep deprivation, hunger, and alertness) and on ergonomic and external factors limiting performance and behavioural freedom. Individual and group behaviour is the result of social interaction. It includes interactions by military commanders and their troops, underlying psychological processes and factors (e.g., fear, morale, and values), and the cultural, educational, and religious background of individuals. There is significant historical evidence that inferior combat potential as measured in terms of numbers of personnel and weapon systems may be compensated for by superior human performance in battle (Dupuy, 1979).

Any time human performance and/or behaviour are at issue, parameters and/or models will be needed to reflect those issues. For example, systems that involve human activity, such as watch or command centres, need to be studied in ways that reflect differences in C2 performance that can be traced to human performance/behaviour issues. In addition, differences can arise from experience or training, coalition features (e.g., language, national doctrine, command style), or service/branch-unique doctrine and practice. These kinds of individual performance and behaviour issues may be modelled in two ways. They can be treated stochastically, in a manner that reflects their occurrence in “real” systems depending on situational factors (black box approach), or in terms of process-oriented behavioural models, describing the psychological processes behind the observable behaviour of individuals or groups in a given situation (Long Term Scientific Study SAS-017 on Human Behaviour Representation, Final Report, Chapter 2). The decision that human performance and behaviour may vary meaningfully will have a clear impact on the choice of models and analytic approaches (e.g., stochastic processes or action-theoretic models such as Norman's Activation Trigger Scheme (ATS) for simulating the dynamics of actions or reactions) (Norman, n.d.).

Where human performance is considered to be a meaningful factor (e.g., C2 within command centres when wearing chemical protection gear), some experimentation may be necessary to develop realistic parameters for the impact on error rates or the pace of work. In other cases, such as simple fatigue, human factors specialists may be able to provide valid parameters from work in other contexts. Such specialists are often valuable members of research teams. In any case where the workflow and work rate within command centres is relevant, human performance parameters must be considered. In addition, human performance issues will have some effect on decisionmaking. Error rates increase as people become tired and overloaded, altering the way they work and the information they consider.

However, research on how to represent human behaviour and its impact on performance in models is still in an early stage. This is particularly true in the context of OOTW. Those operations require the co-operation of non-military actors. In addition, military mission objectives include providing security and assistance in the reconstruction of conditions in the theatre of operations and helping to stabilise the situation to a degree that ultimately permits the military forces to leave. The use of force in OOTW is limited in degree and kind to responding appropriately to threats for defensive and protective purposes and to coercive actions for enforcing compliance with agreements. Military actions that would be highly effective in accomplishing mission objectives in war might be counterproductive in OOTW. In fact, the value of military actions in OOTW is not so much a question of physical effects, but rather how military actions and their physical effects are perceived by the various actors and the population in the theatre, how the military actors interpret the behaviour of the other actors, and the critical mission task conditions (e.g., political interest and media attention). Thus, a careful analysis of mission tasks by human science experts is indispensable for modelling and assessment of C2 options in OOTW (Baeyer, 2001).

It follows that, in addition to the traditional composition operations research/operations analysis (OR/OA) assessment teams, assessors of C2 for OOTW must possess hands-on experience with such operations and relevant non-military organisations (e.g., private aid organisations). The assessment team must also have access to experts from the fields of political science, cultural anthropology, demography, sociology (including media impact research), social psychology, and individual psychology. These experts will contribute the expertise for diagnosing the relevance of, and differences in, performance and behaviour of actors and for the formulation of hypotheses for assessing the “human issue risk” of analysis results.

In addition, they may contribute to the modelling of behavioural processes in analysis tools used to test C2 system sensitivity via parametric variations of human performance and behaviour parameters.

However, well-documented empirical knowledge on human performance in military operations is scarce and little is known about its relevance in circumstances other than those prevailing when the underlying data were collected. Similarly, experience and systematically compiled data on behaviour and response of individuals and groups to actions and situations in OOTW are still limited and theories on human behaviour are mostly untested in the context of military operations. Therefore, dealing with human issues in C2 analyses reduces to the problem of addressing decisions under risk and uncertainty when each of the C2 design options is tested for the range of possible hypotheses on the implications of human issues for C2 effectiveness.

Human Decisionmaking

Increasingly, assessment teams have to deal with issues where individual decisions are important. This is especially true for OOTW in which even tactical-level decisions by a lower level military leader may have strategic implications because of media presence. This represents a major challenge because the variety of human behaviours involved makes modelling decisionmaking very difficult. Fortunately, there are some approaches that can be used to cope with these difficulties. The correct choice, however, will depend on the research issue(s).

In some cases the analyst is asked to assume that decisionmaking will follow established doctrine and tactics, techniques, and procedures (TTPs). In these cases, the challenge is to craft a set of rules or look up tables that reflect the existing guidance correctly. Hence, a model that replicated the "correct" set of decisions would be useful for assessing simple C2 issues such as the impact of new communication and information technology or changes in connectivity or supporting relationships within the force. However, maximising the benefits of technical and organisational changes in a C2 system might require an appropriate adaptation of doctrine and TTPs. Therefore, testing the impact of established rules should be part of the analysis.

Testing the impact of rules is an indispensable prerequisite for models that have built-in sets of rules that are not driven by approved TTPs, but rather by opinions of subject matter experts or modellers whose rationales have been neither validated nor accredited. Considerable knowledge exists on how to organise and validate such expert elicitation. Here again, specialised team members may be helpful. Simple adoption of models developed from subject matter experts will put the assessment team at considerable risk of accepting false conclusions. When such models must be adopted, they should be explored in detail to uncover their driving assumptions and subjected to sensitivity analyses (Chapter 9). Where this cannot be done, these models are best avoided when C2 assessments are performed.

From human factors research on stimuli that influence human decisionmaking we have learned that human decisionmaking capability is degraded in some situations and enhanced in others. These stimuli may originate from, inter alia:

- Biological/physiological processes (e.g., physical overexertion [fatigue], use of bio-chemical substances, and/or sensory deprivation);
- Cognitive sources (e.g., confusion arising in unfamiliar or unknown situations);
- Psychological processes (e.g., processes causing emotions and stress);
- Social processes (e.g., group dynamics that coerce or reinforce individual decisionmaking depending on accepted social norms, organisational infrastructure and procedures);
- Environmental factors (e.g., darkness, austere and/or uncomfortable environments); and
- The decision support tools and technologies that humans use (e.g., information displays and decision support software). It is important to look beyond technology at whether or not human decisionmaking is improved, or even constrained in some cases, by using computerised decision aids depending upon their functionality and configuration.

Types of Decisions

The nature of the decisions being supported by C2 systems will also enable the assessment team to make intelligent decisions about how they influence the analysis. Three useful decision types can be distinguished:

- Automatable decisions;
- Contingent decisions; and
- Complex decisions.

Automatable Decisions

Automatable decisions fall into the category of "simple decisions." The range of decision options is finite and known, and the criteria for selecting among them are clear. Basic sensor-to-shooter decisions are simple decisions that are usually automated for the sake of timely response (e.g., anti-aircraft or missile defence systems). Similarly, the selection of patrol routes, inspection strategies, and many logistics decisions relevant for OOTW can be automated. For example, scheduling can be seen as an optimisation problem in which time, space, and priorities are traded off to generate a "best" answer. Even though the decision environment is constantly changing due to factors such as weather and mechanical problems, scheduling decisions are characterised by rules and algorithms. Models of automatable decisions of this kind can be built relatively easily.

However, where the C2 system employs humans to make these choices, some error rate parameters will be needed if the results are to be meaningful. For example, error rates may increase if the time available to make a decision is insufficient or physical demands induce fatigue. Even where the operational concept calls for the use of automated systems, the analyst should explore the quality of the data, information, or knowledge used to drive the process and the likelihood that humans will be involved in collection or fusion.

In these fully automatable decisions the assumption is that “to know is to decide.” In these cases, if uncertainty were adequately reduced, the correct course of action or decision would be obvious. In that case, decision theory classifies the problem as a “decision under certainty.” These problems are trivial except for the determination of the utility function in case there are more than two selection criteria that need to be considered and/or when constraints need to be accounted for to complete the analysis (Keeny and Raiffa, 1976).

Contingent Decisions

The next level of decisionmaking complexity is best thought of as contingent decisions. These are cases where the commander has thought through the situation and developed a set of alternative actions or decisions that are appropriate to the situation, but further information on the operational environment will be needed to determine which is the proper course of action. In other words, “to know is to decide, but knowing is not yet possible.” In some NATO countries the research community terms this “opportunistic decisionmaking.”

In most cases a lack of clear, precise knowledge is unavoidable. For example, the commander in a defensive posture may recognise that the adversary has several potentially viable options. The adversary may not even know which alternative he will choose. In such a case, the defending commander would both develop courses of action to meet likely contingencies and also undertake a variety of information collection activities designed to provide as much warning as possible when the attacker selects a main attack option.

Modelling contingent decisions is much more difficult than modelling automatable decisions, but is similar in that an underlying set of rules or algorithms still drives the process. The added complexity comes from the need to find the time when information is adequate to select one of several actions. The best models for that purpose are essentially hypothesis testing models. They align information about the operational environment against a finite set of alternative futures and perform probability calculations to determine when the commander has enough confidence to act or to estimate the information gain in terms of the expected value added to decisions as new information arrives (Sherrill, 1996). Information entropy is also a valuable measure of the information state of the commander. It can also be extended to a measure of information dominance (Perry and Moffat, 1997).

Complex Decisions

Finally, “complex” decisions are very difficult to model. These require the decisionmaking system to:

- Recognise when a decision needs to be made;
- Identify the relevant set of options;
- Specify the criteria by which they will be judged; and
- Determine when the decision will be made.

Examples of complex decisions include the definition of missions at the operational level, decisions to change the fundamental activity of the organisation (e.g., shift from the offence to the defence), and the process that creates courses of action in response to events on the battlefield or in OOTW. Except when doctrinal answers are available, complex decisions are very difficult to model and even more difficult to validate or accredit. Most successful efforts dealing with complex decisions have used "human-in-the-loop" techniques and relied on the quality and variety of experts employed for reliability and validity. Some promising research on modelling complex decisions in military operations has been completed in the UK and this is in the process of being incorporated as the core of the next generation of closed form simulation models of conflict being developed by Defence Science and Technology Laboratories (DSTL) (Moffat, 2000; Moffat, 2002) Similar research on tactical decision automata is going on in Germany to improve the capability of simulation systems for analysis as well as training and staff exercises support (Hofmann and Hofman, 2000, von Baeyer, 2001).

Command Style

Assessment teams often encounter the argument that decisionmaking depends on the "commander's style." Moreover, they are told, systems must be designed to support commanders with differing styles. Because it is an elusive and multi-dimensional concept, command style represents a challenge to modelling. However, this factor can be accommodated if the analyst is able to develop a clear concept of the alternative command styles that must be recognised and their consequences for military decisionmaking.

Attributes of the Commander

Differences in command style may be reflected by appropriate attributes such as the background and training of commanders, their decision and order style, risk tolerance, and operational experience. For example, in conjunction with field experience, the background and training of commanders affect the richness of their understanding of the military situation and their capacity to influence it.

Organisational Style

Another not totally unrelated topology deals with the degree to which the commander uses a formal decomposition of the situation versus a holistic, integrated vision. The decomposition style of management is associated with hierarchical and segmented work, as in the Napoleonic or classic German general staff. This heavily structured process allows centralised control and tight coupling between the structure of the problem, the structure of the supporting staff, and the flow of information within and between command centres. The classic centralised commander imposes his style on the C2 process and impacts key organisational issues as well as decision style.

The alternative command style is an open and holistic one in which senior staff and commanders from related command levels are directly involved in a broad development of courses of action and implementation plans. This more open process also has implications for the information flow within and between command centres. While decisions are still made authoritatively at the centre (by the commander or senior staff), they tend to generate loose guidance (mission type orders) and to enable lower level commanders and their staffs more latitude in implementation.

Risk Style

Another topology applied by some practitioners is the degree to which individual commanders (and doctrines) are risk averse versus attracted to risk. Most military enterprises have some properties that impel commanders to minimise risk. The fact that lives, national treasure, and serious national interests are involved in warfare suggests that risk averse strategies will tend to dominate. However, some military commanders are more comfortable with greater risk. Indeed, outnumbered or otherwise disadvantaged forces must often take risks in order to prevail. To the extent that the relative risk aversion of commanders is relevant to the C2 analyses underway, assessment teams will need to define and model variables that represent this factor (Schultz, n.d.).

Recent research on Bayesian decisionmaking had indicated that the perception of risk as measured by utility loss relative to a goal value and perception of future outcomes can in combination give insight into the way these affect command decisionmaking (Moffat, 2002).

Orders Style

Commanders, and national command styles, have also been shown to differ in the degree of detail contained in directives to subordinates. At one end of the spectrum is the commander who issues detailed orders that specify what is to be done, how it is to be accomplished, and when and where the specified activities are to occur. At the opposite end of the spectrum is the commander who issues “mission type orders” which simply specify the mission to be accomplished and leave decisions about the detailed objectives, forces to be employed, critical terrain, and timing up to the subordinate commanders. In between are those who specify a series of linked objectives (cross the river, take the high ground in the north, and be prepared to defend or carry the attack north-east into the valley) and supporting detail (e.g., forces available, rough timetable keyed to the objectives) but leave subordinates with considerable discretion within that guidance. Both the speed of the C2 process and the distribution of C2 work across command centres (particularly planning and operations management) will vary greatly depending on the commander's style on this dimension. National doctrine and practice may also influence this factor.

Other Typologies

Other typologies of command styles are, of course, possible and may be more relevant to particular C2 analyses. Human behaviour experts (e.g., cognitive and organisational psychologists and anthropologists) should be recruited to the project team if novel categories are developed. However, the most important issue when dealing with command style is whether it is included in the analysis at all. The C2 research related hypotheses under analysis should dictate the forms of command style examined. However, the impact of command style should only be examined because it appears to be necessary to answer the analytic question(s) of interest. Otherwise it tends to introduce a level of complexity that may confound the other analyses underway.

Organisational Factors

All elements of the C2 system are ultimately related to one another. The linkage between human and organisational issues, however, is particularly direct and close. Properly done, organisational design reflects the interaction among the tasks to be done, the people available to perform them, and the systems or tools that support those people. Hence, the "proper" organisation of C2 depends in large measure on the capabilities, training, and experience of the people in the C2 system.

Organisation is a serious subject in military analyses. For centuries the military has sought to implement unambiguous relationships and responsibilities. Unity of command is a central principle of war. When it has been lost or comes into question, as in OOTW, the professional militaries of the world have found themselves very uncomfortable. Fortunately, military organisational issues are driven by a fairly small and finite list of principles. Assessment teams asked to work on C2 issues can use the known list of factors as a checklist about organisational differences to determine whether they need to build organisational matters into their research designs. This includes the issue of informal relationships that may have evolved in order to overcome organisational deficits and thus streamline day-to-day operations. In fact, an organisational design and command style that are supportive of building informal relationships may provide the flexibility for efficiently handling the manifold demands facing commanders in OOTW. Also, it should be recognised that organisational implications which are perceived as detrimental to the interests of the affected individuals and groups inevitably would jeopardise cooperation, technical and procedural improvements in C2 notwithstanding.

Organisational Differences

The principal differences between military organisations are related to structure, function, and capacity. Any change or innovation that can be introduced in a C2 organisation falls into one of these three categories which, therefore, may be used to guide analysts when structuring a problem.

Structural differences include:

- The number of echelons or layers in the command structure;
- The span of control for nodes in the command structure;
- The pattern of linkages between those nodes (e.g., hierarchical, spokes of a wheel, multi-connected, networked);
  - Permanent versus transitory organisational relationship; and
  - Formal versus informal relationships.

Functional differences include:

- The distribution of responsibility: where functional activities are located (e.g., intelligence, logistics, command, civil military cooperation [CIMIC]);
  - The distribution of authority (ideally co-located with responsibility);

  - The distribution of information;
  - Functional specificity (e.g., fire support vs. infantry or close air support vs. defensive counter air) vs. general and integrated military capabilities (mission tailored task forces); and

- Degree of ambiguity in command relationships.

Difference in capacity is related to differences in:

- Personnel (e.g., quality, training, experience);
- Communications systems and architectures;
- Information processing systems and architectures; and
- Field training and operational experience.

All these dimensions can be modelled, some more easily than others. However, the assessment team's challenge is to identify those organisational factors that are relevant to the C2 analyses underway. This issue must also be addressed knowing that organisational factors are interrelated: changing one may change others. For example, the decision to eliminate a level of hierarchy within a military organisation may have a profound influence on the span of control. Similarly, changing the distribution of information so that it no longer follows the chain of command may have profound implications for the ambiguity of command relationships. Similar effects can be expected when coalition operations involve ad hoc members.

Treatment of Organisational Factors

Because of the large numbers of organisational variables that may be relevant to the analysis of C2 issues, they must be approached carefully and systematically. When possible, organisation theory expertise should be brought into the assessment team. Review of organisational issues is treated in a two-step process guided by a hypothesis testing logic. The first step should assess whether any organisational variable is being manipulated directly. For example, a decision to move from warfare domain task forces[1] to mission tailored task forces with air and land units planning and operating together under a joint commander would be seen as a direct manipulation of organisational factors and should be studied as such. The second step, a search for indirect effects of organisational factors, may be more difficult and will require that the assessment team use the list of possible factors as a checklist and think through whether they may be altered in a prepositional (if, then) logic. An assessment team that posits a relationship between the C2 analysis and an organisational issue should be able to make a clear statement of the hypothesis and the causality anticipated. This will enable the research design to cover not only the gross effect anticipated, but also the underlying causal mechanism(s) that will be present if the proposition is correct. Adopting this hypothesis approach is also a safeguard against assuming that organisational issues are easily or well understood and can be treated by assumption. In fact, the organisational arena, like that of human factors, is one of the most difficult in C2 analysis and must be approached with care and rigour.

For example, the small group literature makes a clear prediction that multi-connected groups will be able to generate better answers to complex problems, but will take more time to do so than either hierarchies or star shaped groups. The causal mechanism in that theory is greater dialogue and the representation of more independent viewpoints. Moreover, these richer discussions are expected to take more time. All other things being equal, multi-connected groups that are found to generate better answers to complex problems should also engage in more dialogue and be found to have considered more information and or solutions. Modellers who want to take advantage of this factor to explore alternatives to traditional hierarchical military decisionmaking must also include the negative features in their C2 models (e.g., demands for more time from already overburdened staffs and slower decisionmaking).

Roles

The concept of a role comes from sociology. A role is a set of behaviours expected by the self and others. For most military systems the roles of commander and key staff are well understood and arise from a combination of tradition, training, experience, and rational planning. Because of their origin, roles are often a convenient way of capturing the doctrine about responsibilities within the C2 system.

Roles can be used to capture “syndromes” or sets of related attributes within a C2 system. For example, an object oriented program might have different functional organisations and their leaders might be defined as having different attributes that reflect their decisionmaking responsibilities and the information they would receive or be able to obtain from the information network. When assessing new C2 systems, analysts will often need to search for potential role gaps or role overlaps. Either of these would be dysfunctional in military operations over time. Changes in information structures also have considerable potential for creating problems of this type.

Role gaps, role overlaps, and even role conflicts may be more of a problem in OOTW because military organizations have to assume new roles not embedded in their tradition and experience and requiring them to cooperate with a variety of non-military actors and organizations pursuing their particular objectives and the roles of which are ill defined in many cases. Thus, rather than being a source of friction, changing or adapting existing information structures may be part of the decision problems that the C2 system must address in order to eventually bring about a secure and stable situation in the theatre of operations through overarching "unity of command."

Human and Organisational Issues and Technology

The foregoing discussion of human and organizational issues revealed that human performance and behaviour as well as the organizational design of C2 systems, and therefore the effectiveness of C2, depend on the available communication and information technology. In fact, a C2 organization resembles a system composed of interacting human, organizational, and technological elements as depicted schematically in Figure 6.1 adapted from Mandeles et al. (1996).

Figure 6.1 is meant to illustrate that the character and performance of a C2 system may change as anyone of elements in these three categories changes. Moreover, since the human, organizational and technological elements are closely linked in most cases, optimising each one of them at a time under ceteris paribus assumptions for the other two rarely ever results in an efficient C2 system (Schot and Rip, 1996).

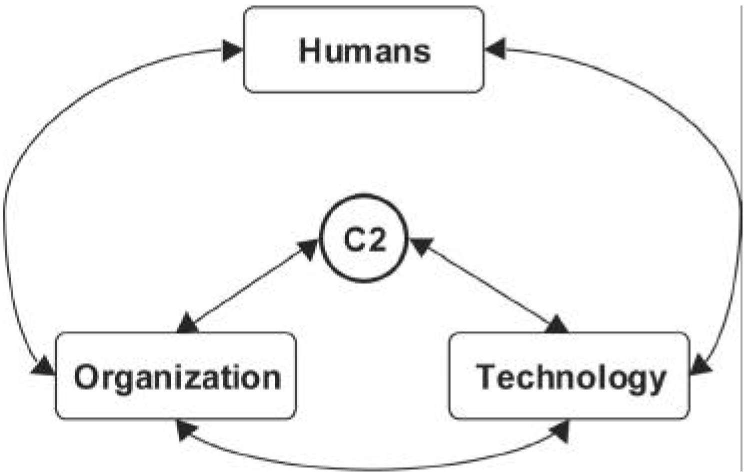


Figure 6.1. Representation of the C2 System, based on Mandeles et al. (1996)

In particular, the assessment of the human-technology relationship is a critical requirement that implies challenges that can be both social and technical in nature. Without adapting human thought and behaviour patterns and organizational structures it may be impossible to exploit the potential of new technology. On the other hand, the performance of new communication and information technologies may exceed human capabilities of processing information (information overflow) and thus result in a degradation of human performance and overall effectiveness of a C2 system, the improvement of technical parameters notwithstanding.

The challenges of adapting technological capabilities to meet human capabilities and the requirements of the social interaction processes of commanders and staff, and non-military actors and populations in OOTW, require socio-technical assessment approaches of the kind that evolved in the fields of science and technology studies (STS), technology assessment (TA) (Rip.1995), and constructive technology assessment (CTA) (Van de Poel, 1999).

Integrated Analyses

Because the issues arising from human and organisational factors are so complex and so tightly coupled, C2 assessment teams often use integrating tools to define the key dimensions relevant to their analyses and explore the relationships between and among them. Integrating tools are those that use selected key factors with powerful influence to cut through the clutter and detail implied by trying to study everything and concentrate instead on the most important elements in the problem. These key driving factors are used to conduct a simpler analysis that can then be augmented by sensitivity analyses and analytic excursions to ensure that the problem has been fully and properly understood.

For example, Figure 6.2 has been used to illustrate the relationship between the time available to make a decision, the complexity of the decision, and the uncertainty of the information available about the situation. These three factors also reflect the risk or opportunity inherent in a military situation. The more complex a situation, the less time available, and the greater the uncertainty of the available information, the greater the risks (and opportunities) present.

While each of these three dimensions can be examined independently, considerable insight can be derived from examining them as a related set. This examination normally begins as an exercise in hypothesis generation, but can, as research is accomplished, be converted into a component of a knowledge base. That is, as evidence confirming or calling for revising the key hypotheses is generated, the graphic becomes a way of conveying known relationships and generating new propositions about regions or subspaces that have not yet been examined empirically.

In some sense, one corner of this cube represents the worst of all C2 worlds—almost no time available, an enormously complex problem, and considerable uncertainty about the situation. Past research suggests that when these conditions exist the decisionmaker has no choice except to use "best professional judgement" to match the operational situation to some class of well-understood military situations and act accordingly. (Hayes, 1994). However, decisionmaking theory also indicates that the wise commander will take short-term actions designed to create more time and/or more information and thereby relocate the problem to a "better" portion of the space. A "risk averse" commander will clearly attempt this transformation of the situation. However, a more risk oriented leader may attempt to cut through the fog of war with decisive action.

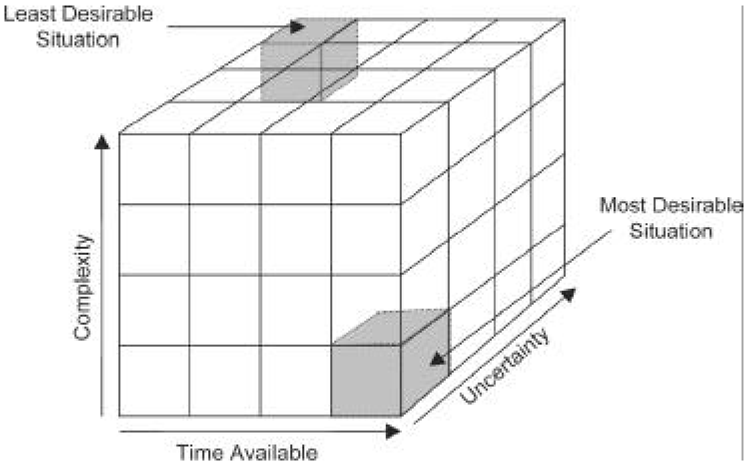


Figure 6.2. Decisionmaking Drivers

The opposite corner of this analytic space, defined as ample decision time available, limited complexity, and low uncertainty, provides the ideal situation for decomposition of the problem and development of "optimal" military plans. Many innovations in C2 systems are designed to move the situations facing commanders of friendly forces toward this region. Indeed, Van Creveld's analysis of C2 defines it as a search for greater certainty (Van Creveld, 1985).

This cube also emphasises an imperfectly understood dimension of C2 systems and the decisionmaking they imply. That dimension is the speed at which the situation is changing (the pace of operations) in relation to the time required to make and implement a military decision (the speed of the C2 system). Where the speed of the C2 system is faster, proactive decisions are possible. When the pace of operations is faster, decisions must be reactive. The commander who is capable of making decisions that transform the operation from reactive to proactive is rare and enjoys vision not only about what is, but also about what is possible.

This key relationship (pace of operations to speed of the C2 system) is the driving force behind the observe, orient, decide, act (OODA) loop and the resulting guidance to seek to “turn inside the enemy’s C2 loop.” However, C2 analysts must constantly discipline their analyses away from assuming that speed alone is a desirable attribute of a C2 system or organisation. Making and implementing bad decisions quickly will result in more rapid failures, not military success. As is discussed in detail in Chapter 5: Measures of Merit, multiple dimensions of performance need to be analysed whenever C2 systems are assessed. However, this requirement to look at multiple dimensions in order to assess C2 does not obviate the value of performing integrated analyses of human factors and organisational issues.

Conclusions

- Issues of human performance and behaviour should be incorporated in models used to analyse issues that require human activity either in the form of performance parameters or appropriate sub-models on behaviour.
- Decisionmaking that is rule or algorithmically based can be modelled directly, but error rates should be estimated if humans are involved in the relevant decisionmaking.
- Simple decisions are programmable (with appropriate error rates), but also require estimations of when decision would be made.

- Complex decisions can be treated with “human in the loop” tools and techniques, but new techniques are being developed and applied (see Chapter 5).
- Style of command and decisionmaking should be considered in C2 analyses that focus on specific decisionmaking.
- Organisational issues can be decomposed into constituent elements for analysis.
- Hypotheses or propositional structures are often the most useful approach to human factors and organisational issues.
- Integrated analyses involving roles or selected aspects of a problem space often provide a cohesive approach to the complexity inherent in human factors and organisational issues.
- Research in organisations and human factors is expanding and analysts are advised to consult the available literature. Experts in this area should be included on the interdisciplinary C2 assessment teams.
- Operational knowledge of human issues is still weak in many areas. Systematic effort is required for organising a consistent program for experiments on human issues.

Recommendations

- Human and organisational issues are not closed topics and should be considered early in the process of C2 analysis when the problem is formulated and a strategy is adopted.

- Test the impact of established decisionmaking rules that reflect existing guidance as part of an analysis. This is an indispensable prerequisite for models.
- The assessment team should explore the quality of data, information, or knowledge used to drive the automatable decisionmaking process.
- Early on, the assessment team should establish working relationships with the potential subjects of the study but be careful not to allow this to introduce a bias.
- Human factors and organisational expertise should be included in all C2 assessment teams; at least until a decision can be made that they are not major elements of the analysis.
- Separate human performance issues (e.g., stress and fatigue) from cognitive issues (e.g., decisionmaking) when possible, but recognise that they interact.
- Use a checklist (Annex D) and hypothesis-testing logic for reviewing human and organisational issues. Remember that human and organisational issues may interact as do the structural, functional, and capacity arenas of organisations.
- Integrated analytic tools that focus on key variables that drive human factors and organisational issues will often prove useful in simplifying analysis.

- Sensitivity analyses are particularly important when working with human factors and organisational issues.
- Experiments for testing hypotheses on human behaviour underlying the C2 analysis are strongly recommended.

Chapter 6 Acronyms

ATS – Norman's Activation Trigger Scheme

C2 – Command and Control

CIMIC – Civil-Military Cooperation

CISS – Center for Information Systems Security

CTA – Constructive Technology Assessment

DISA – Defence Information Systems Agency

DSTL – Defence Science and Technology Laboratories

MoM – Measures of Merit

OA – Operations Assessment

OODA loop – Observe, Orient, Decide, Act

OOTW – Operations Other Than War

OR/OA – Operations Research/Operations Assessment

STS – Science and Technology Studies

TA – Technology Assessment

TTP – Tactics, Techniques, and Procedures

VTC – Video Teleconference

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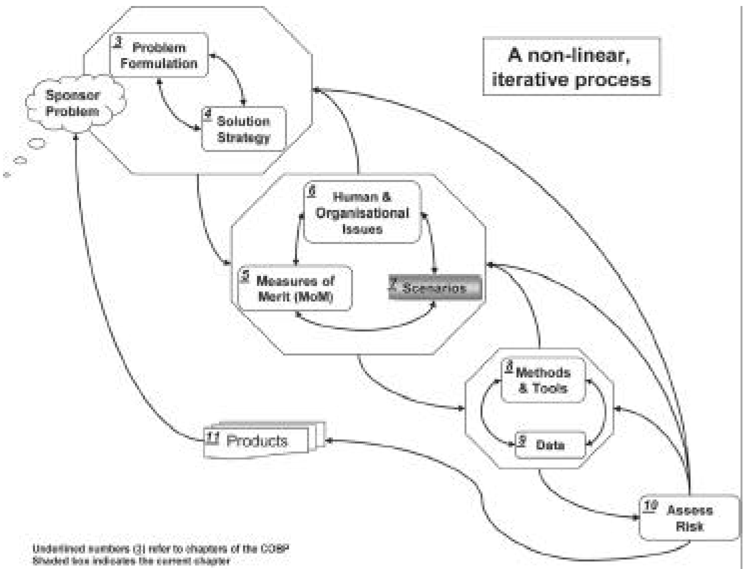
[1]Land warfare with one commander, air warfare with another, each reporting directly to a joint commander.

CHAPTER 7

Scenarios



Before beginning operations you must, without any indulgence or self-deception, examine objectively every step that the enemy might undertake to thwart your plan, and consider in each conceivable case what means are open to you to fulfill your goal. The more you anticipate the difficulties in advance, the less surprised you will be should you encounter them during the campaign. Besides, you have already thought about these obstacles deliberately, and with composure you *have perceived the means of avoiding them, so nothing can surprise you.*

—Frederick the Great

Plans that assume the likelihood of one particular world run the risk of being seriously wrong.

—James A. Dewar, Carl H. Builder, William M. Hix, Morlie H. Levin from *Assumption-Based Planning—A Planning Tool for Very Uncertain Times*

Purpose of Scenarios

The report of the NATO Panel 7 Ad Hoc Working Group on the Impact of C3I on the Battlefield gave extensive consideration to the role of scenarios in operations analysis (OA). This chapter builds on that material to discuss the role of scenarios in Command and Control (C2) analysis. Figure 2.2 in Chapter 2 shows the role played by scenarios in the overall C2 assessment process. The analysts craft a set of scenarios to provide the context or environment for the conduct of the operational analysis. The scenarios bound the arena of the analysis and are used by the analyst to focus the analysis on central issues.

Definitions

These definitions are of particular relevance to this Code of Best Practice (COBP):

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.

As described in Chapter 4, scenarios consists of four elements—a context (e.g., a characterisation of a geopolitical situation), the participants (e.g., intentions, capabilities of blue, red, others), the environment (e.g., natural—weather and manmade—mines), and the evolution of events in time. In C2 assessments, the purpose of scenarios is to ensure that the analysis is informed by the appropriate range of opportunities to observe the relevant variables and their interrelationships.

Approved Scenario

In order to support the analysis, the use of an approved scenario is more relevant than to analyse a current situation or future plans. The impact of all the elements is simpler to analyse.

In some countries these scenarios are mainly developed by a Strategic Committee and are designed to meet the government strategy. The first step is to implement a steering group, composed of representatives of the government and members of the Armed Forces, which has the responsibility to describe all the commitments or the precise regions in which any major event may have an impact on the foreign politic or on the economy. This basic work is then forwarded to a larger group or a next military level which shares the responsibility for implementing the main recommendations in a more strategic field. These scenarios specify the elements that must be kept in mind in the generic planning process or in the operational studies in relation with the use of military forces. These scenarios also describe the global threat, the geographic areas, the political and military objectives and the level of force commitment.

With this basic approach done, the analyst or his military counterpart has only to adapt those guidelines, to compare his study to the scenarios and to propose the more relevant alterations to his sponsor and his assessment team (See *Assessment Team* paragraph in Chapter 2).

At this stage the decision to keep this scenario, to diverge or to choose another one will be discussed among the stakeholders. The products of this process are called approved scenarios.

After that, at any time the analysts may develop vignettes using the approved scenarios as a base in order to focus on a specific issue. These vignettes can be used as small scenarios to explore a particular topic. The use of prepared scenarios must not be considered as a limitation for customers or analysts because all the data could be adapted by the customer or the assessment team, the only limitation is to avoid the re-use of this particular scenario for a study not in close relation with the original one.

Planning Scenario

A planning scenario is one in which these elements are defined:

- Time frame of the analysis;
- Geographic area;
- Meteorological environment;

- Political, historical, economic, and social context;
- Mission objectives and constraints;
- Level of threat;
- Friendly forces (and links between each members of the coalition);
- Adversary forces (e.g., enemy order of battle);
- Neutral or uncommitted forces;
- Non-combatant (non-government organisations [NGOs], international organisations, etc.) and other relevant actors; and
- Media (when relevant).

Operational Scenario

An operational scenario contains additional details especially with respect to threats, orders of battle, tactics, rules of engagement, courses of action, deployment, end state and reserves.

Vignette

The term “vignette” is sometimes used for a scenario that is not approved. The term is also primarily used for smaller scenarios, particularly as excursions from the main scenario.

Role of Scenarios in C2 Analysis

In general, the ideal OA is scenario independent. All relevant factors can be identified and dealt with empirically and algorithmically across a range of military contexts. However, C2 involves human behaviour, organisations, missions, and other complex phenomena. Human behaviour is very difficult to put into equations (see "Human Decisionmaking" in Chapter 6). There is no single linear dimension for organisations or human issues. Moreover, military missions do not form simple dimensions. Therefore, for most C2 analyses, the context must be defined. This is the role for which the analyst defines the scenarios.

The formulation of the original problem dictates the contents of the scenarios. There are no overall scenarios that are independent of a specific problem. Scenarios are never truly generic, but rather are customised if only by the assumptions built into them. The boundaries of the scenario space should be defined in part by the issues unique to the problem under analysis.

Organisational issues include the involvement of various levels of military and non-military hierarchies, including different command levels. This requires that scenarios accommodate analysis across different echelons of command. Information processing and the characteristics of information must also be accommodated. Human factors include the decisionmaking process and supporting staff activities.

The analyst will need to design or select scenarios to address C2 under a broad range of circumstances. This taxonomy of C2 analysis might include:

- Defense-planning;
- Force structure and organisation;

- Mission analysis;
- Doctrine/tactics development;
- Cost-benefit/effectiveness analysis;
- Training and education;
- Balancing C2 systems and weapon/sensor systems;
- C2 system procurement, which will often require more detailed, task specific scenarios to cover the range of relevant system uses; and
- Non-combatant actor's access to C2 systems and integration into the information flow, typically through liaison officers, but increasingly through a variety of other means.

In essence, the role of a scenario is to define a set of conditions and restrictions to enable "good" analysis as well as to create a structure within which the results of the analysis can be understood and interpreted.

Understanding and Interpreting the Results of Operational Analysis

The analyst uses scenarios to understand and interpret the value of OA study results for the focus of the analysis. The scenarios provide the context in which the C2 system will be assessed. It should reflect the scenarios envisaged by the originator of the requirement for the system. Often artificial constraints must be introduced into the scenarios, due to cost considerations, to properly focus the analysis, or both. The scenario developer must have an appreciation of the objectives of the simulation, experiment, or exercise analysis plan in order to determine the artificial constraints necessary to facilitate the analysis. The analyst needs to be aware of scenario assumptions and artificial constraints.

There are several essential questions in C2 analysis that should be addressed in the scenario considerations:

- operational benefits of C2 to be translated in the definitions of Measures of Policy Effectiveness (MoPE) and Measures of Force Effectiveness (MoFE);
- required or desired performance thresholds and nominal Measures of Merit (MoM) values; and
- the impact of an improved volume, accuracy, and/or quality of information on the final outcome.

Developing and Specifying Scenarios

Prerequisites in Scenario Definition

Several prerequisites are essential before using scenarios for C2 analysis:

- Approval: the analyst should strive for the creation of a family of approved scenarios. In creating a family of approved scenarios, which reflect the mission objectives and force capabilities and cover all significant warfare areas, the analyst facilitates the scenario development process to a great extent, because references to basic assumptions and conditions can be made. This will also increase the validity of the analysis in the eyes of the client and facilitate comparison of the results from different studies and analyses that use the same approved scenarios;

- Breadth: a scenario should reflect those factors that are hypothesised to have a significant impact on C2 issues;
- Capability: a scenario should stress C2 capabilities, including human and organisational factors (military and/or civilian) where appropriate; and
- Credibility: scenarios should include logical assumptions about the environment under analysis.

Scenarios should represent plausible real world situations. The synthetic scenario environment should be consistent across OA studies. The scenarios will gain credibility if a broadly based scenario team is involved in the process from the outset. This team should include a variety of perspectives and expertise, such as:

- OA analysts for defining the required scenario information, to avoid biasing the analysis by selecting an inappropriate scenario space, and for working out the process of framing of the scenario space;
- Defence concept planners to propose options and highlight the critical factors;
- Policy makers to ensure that the strategic decision points and the alternative options for each of these decision points are clear and consistent with Defence Policy; and

- Subject matter experts to credibly explore the range of possibilities (scenario space) and foster discussions.

C2 Organisation Infrastructure and Operating Environment

Organisation infrastructure and environment are often pre-set conditions and not the subject of the study. They include C2 concepts of operation, decision hierarchy of the units under consideration, degree of technological competence relative to that of the adversary, requirements or objectives placed upon the system in terms of speed, accuracy, flexibility, etc., and the impacts of terrain, weather, and adversary activities.

C2 Processes

The scenarios need to provide for the realistic execution of the C2 processes. These include the span of control of the various military command levels and civilian authorities, information management schemes, information flows, the elements of the decision cycle, the decision processes (course of action development, planning, directing), and the communications processes and capabilities (data update rates, throughput, reliability, accuracy, etc.). All too often these issues are characterised by simple performance indicators and not examined in detail. They may also be an important subject of the study. These factors need to be explicitly built into the scenarios.

C2 Systems

Characteristics of C2 systems are directly related to system improvements. They include system performance parameters, command and control information systems (CCIS), data availability, intelligence functions (fusion, correlation, aggregation, etc.), surveillance, targeting and acquisition (STA), communications systems, throughput, and so forth.

Human Factors

C2 studies are complex in nature. One of the complicating factors is the involvement of human beings and their interpretation of a situation, order, or rule of engagement. These factors can be covered by the "aggregation/de-aggregation" phenomena in the command chain. Human factors have to be included in the analysis and modelling activities, but guidelines on how to integrate the "human in the loop" are partly defined in the scenarios. (Chapter 6—Human Decisionmaking discusses these in some detail.)

Miscellaneous

C2 studies usually cover various levels of hierarchy. However, the nature of C2 issues does not materially change for the various command levels. The analyst may need to perform a cost/benefit analysis on the inclusion of lower level C2 issues in a closed simulation model. The analyst needs to consider to what extent these issues (e.g., performance of a logistic information system) need to be converted to enabling factors (e.g., sustainability, operational delays) at the higher levels.

These issues are mentioned to illustrate that in the scenario definition a great deal of attention is required to ensure that the scenario enables the proper C2 issue to be addressed in problem definition. The elements are often dependent on each other. For example, some shortcomings in C2 systems can be compensated for by alterations in C2 processes. Similarly, inefficiencies in C2 processes can be met by an adaptable C2 organisation. The relationships between these issues should be recognised and taken into account in the scenarios.

Approach to Scenario Development

This section describes a framework for the definition of a scenario. Then, based on this framework, some specific aspects of actually using scenarios for C2 analysis are addressed.

Scenario Structure

The general scenario framework developed from the NATO Panel 7 Ad Hoc Working Group on the Impact of C3I on the Battlefield has been adopted (Figure 7.1).

At the first two levels, a description of the external factors and the capabilities of the actors, including national security interests; the political, historical, and military situation; and the acting assumptions, boundary conditions, and limitations related to adversaries, threats, risks, coalition partners, warfare domains etc. are given. Very often a reference to an approved scenario will suffice.

At the third level, the mission environment is defined. Whether it is a generic, virtual geographic environment or a specific geographical area is not important. What is essential is that the mission environment be addressed.

External Factors	**Environment**	**Mission Objectives**		**Mission**
	Economic/Military/ Political/Social/ Historic Situation	Mission Constraints & Limitations ROE		Military Scope, Intensity, Joint/Command } Tasks
	National Security Interests			
Capabilities of Actors	• Organisation, Order of Battle, C2, Doctrine, Resources, Lessons Learned • Weapons • Logistics • Skills • Morale			
	Friendly Forces	Adversary Forces	Neutral Forces	Non-Combatants
Environment	• Geography/Region/Terrain • Climate/Weather • (Civil) Infrastructure (e.g., Transportation, Telecommunications, Energy)			

Figure 7.1. The Scenario Framework

The intermediate level is the most challenging one. The actual military problem has to be projected on the mission, the military forces and capabilities, the civilian capabilities, and the resources available. A scenario must be developed by coherently aggregating a number of components or dimensions with their attached values, taking into account of the problem formulation. It should address at least these components:

- Geopolitical situation, including historical aspects;
- Geographical area;
  - Availability/usability of civil infrastructure;
  - Terrain and climate;
- Political/economical/military objectives;
  - Level of violence, type of warfare areas, and preparation times;
- Mission context and objectives;
  - Mission tasks and goals;

    - National contributions and roles within the coalition;
    - Order of battle;
    - Doctrines, procedures, (range of acceptable) rules of engagement, and concepts of operation;
    - Temporal factors (e.g., anticipated duration of operations);
    - Desired end states;
- Opposition/threat/risks;
    - Adversary forces and their organisation;
    - Other actors (neutral and uncommitted forces, non-combatants, refugees, IOs, NGO's, Red Cross, etc.);
    - Level of threat and risk;
    - C2 structures;
    - Interaction between friendly, adversary, and other information systems; and
    - Assumptions/hypotheses/axioms about level of technology, impact on information defence, etc.

The actual military problem will be placed in the context of the friendly and adversary military forces involved, e.g.:

- Force organisation, C2 structure, force components;
- Doctrines, tactics, rules of engagements;
- Courses of action;
- Information systems; and

- Logistics.

The framing of scenarios begins with the identification of the key dimensions relative to the problem being addressed. The search of these dimensions is delicate and requires thorough reflection, for instance, on the results of a structural analysis. Once identified, each key dimension or factor must be characterised by a range of possible values or sectors, which enables the set up of the sector-factor matrix. This sector factor matrix is then analysed through a morphological analysis (construction and reduction of the morphological space or space of "all possible scenarios"), which provides the user with a set of appropriate scenarios. The scenarios are dependent upon the problem and the objective of the study and can range from generic to very specific. The analyst will select the level of detail required to drive and focus the model.

Using Scenarios in C2 Assessment

It has already been noted that a well-formulated OA problem definition, guidelines and directives for how to approach the analysis should accompany a scenario. Emphasis in this COBP is given to C2 elements in relation to:

- Mission scope: as stated before, one of the characteristics of C2 is that it can not be studied in isolation. C2 is an integrating and enabling factor. As a consequence there is a tendency to consider the entire mission, covering all the arenas connected to it (from logistics to manoeuvre, from artillery support to close combat, from security/police issues to refugee management). Therefore, the typical mission scope for C2 analysis will be broad;

- Levels of hierarchy: the C2 chain is not limited to a special hierarchical level; information and command flows are running from the lowest levels to the higher echelons and vice versa. As a consequence, there is a tendency to cover a wide set of hierarchy levels in considering a C2 problem. Single layer analyses do not represent the dynamics of military problems adequately to answer most C2 issues; and

- Aggregation/disaggregation: the aggregation of data flows, data fusion in support of intelligence processes, merging C2 items to more abstract levels, etc. is difficult but manageable. The process of deleting, merging, and combining information is reasonably well understood. The integration of soft factors (e.g., human and organisational) is less well understood and makes the problem more difficult to simulate, study, or analyse. In particular, the effects of interactions between functional groups and echelons must be considered when decomposition is undertaken for analytic purposes.

Mission Scope versus Levels of Hierarchy

Experience with prior modelling efforts indicates that the scenario developer needs to understand the relationships between the scope of the mission, the hierarchy assigned to conduct the mission, and the level of detail at which the echelon operates. In general, as shown in Figure 7.2, the broader the mission scope, the higher the echelon required to conduct the mission. Also, higher command levels tend to use information at higher levels of aggregation, or less detail, than lower levels. The scenario developer should attempt to operate in the shaded area of the diagram, matching the echelon levels to the proper aggregation level and mission scope.

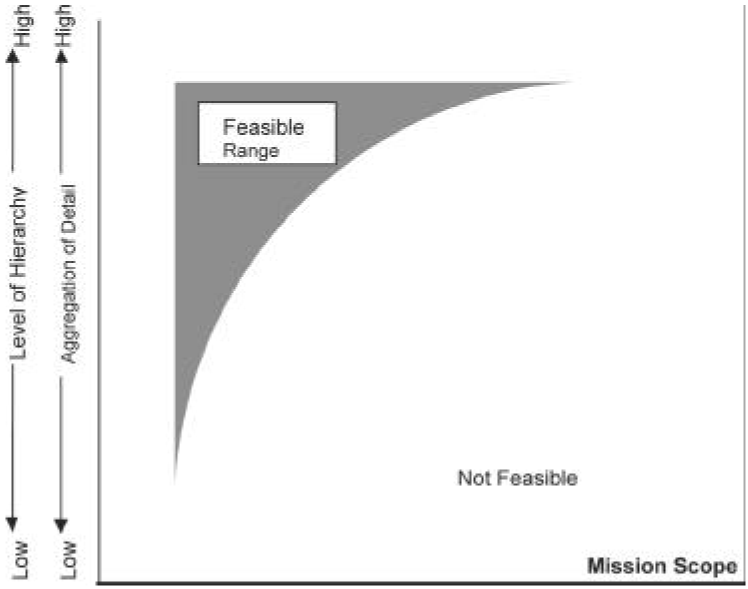


Figure 7.2 Intersections in Hierarchy

In many complex problems, the analyst is required to subdivide the problem into smaller parts, perhaps even using different models or model federations to represent different levels. The scenario developer should work in conjunction with the analyst to ensure that the hierarchical intersections and interactions (e.g., organisation and infrastructure, C2 processes, and C2 resources) are properly represented, that the models are consistent, and their inputs and outputs are properly linked. Figure 7.3 graphically depicts this relationship, with the rectangles X, Y, and Z representing different models.

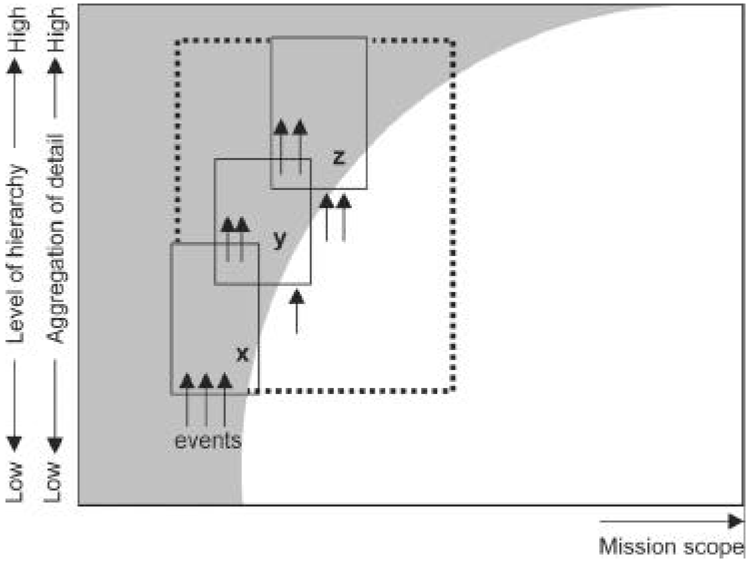


Figure 7.3 Segmentation Hierarchy Range

Aggregation/De-Aggregation: Non-Causality Between C2 Issues At Different Levels

Analysis of C2 issues generally requires assessing the effects of events and actions across command levels to determine causality between actions at one echelon and events at another. For example, the analyst will want to know if the capability to make faster decisions at battalion level has an impact at brigade level or higher. Some C2 items have an impact throughout the entire hierarchical range, some affect only one other level, and some are purely local, i.e., level-specific. The scenario developer will need to be aware of the analyst's requirements in this area in order to design the proper linkages between events.

Additional Aspects

Additional Areas of Consideration:

- Specification: the purpose of the C2 analysis will influence the kind of scenarios to be used. There are no universal generic scenarios for C2 analysis. Some nations have “validated” scenarios that can be taken off the shelf and modified to support particular analyses;

- Merging mission operations areas: mission areas for the various levels of intensity of conflict and various level of civilians involvement are not discrete, and it may be necessary to include elements of more than one type into a scenario;

- Decomposition: sometimes it might be useful to decompose a scenario into two or more detailed scenarios that each deal with a certain subset of C2 issues. This is more or less analogous to the decomposition into one or more mission operations areas. It may be necessary to add some vignettes to look in greater detail such that all C2 issues of interests are covered and that the whole range of relevant OOTW is explored;

- Adversary-friendly interaction: the attention given to adversary and friendly C2 processes should be balanced in those cases where adversary activities are germane to the problem, especially if counter C2 (information defence) is part of the analytic focus;

- Assumptions and guidelines: the scenarios are part of the process in developing an analysis (See

Figure 2.3 in Chapter 2). In the scenario phase, all scenario assumptions, guidelines, and boundaries for the study should be revisited. Each study is executed within the framework of the scenario, and therefore the study findings are only valid within the limitations of the various assumptions and artificial constraints of the scenario;

- Traceability: analysts should understand which scenario assumptions and/or boundary conditions are driving factors in the analysis. A detailed description of past use of scenarios should be maintained on a national level in order to avoid duplication. Such a repository should also contain Verification, Validation, and Accreditation (VV&A) information on the scenarios; and

- Awareness: create awareness of the robustness of the overall conclusions and decisions and be aware of the degrees of uncertainty in the scenario.

Conclusions

- Using a scenario for C2 analysis is only one part of a larger analytical methodology. The context provided by the scenario impacts in other areas, and the scenario in turn is affected by those same areas;

- Six prerequisites should be in place before using a scenario for C2 analysis:

    - It should be approved for the assessment;

    - It should reflect the factors that have significant impact on C2 needs;

  - It should stress C2 issues;
  - It should be militarily credible;
  - It should be credible in terms of civil-military objectives;
  - It should facilitate the design process;
- At least three C2 elements should be reflected in a scenario in order to make it useful for C2 analysis:
  - The C2 organisation and infrastructure, including human issues;
  - The C2 processes;
  - The C2 systems;
- Scenario guiding directives should indicate how the scenario has been used in a hierarchy of scenarios (interpretation of input and output events, etc.);
- The actual C2 analysis problem usually will be broader in scope than OA will allow. Hence Scenario Analysis in combination with military and civilian judgement (including lessons learned) must bridge this gap; and
- Analysts need to use multiple scenarios; no single scenario is sufficient.

Recommendations

Practice

- Organise a set of scenarios and vignettes that allow the analysis to cover or sample the interesting problem space for the C2 analysis;

- Create a (national) base of approved scenarios and vignettes reflecting the civil-military objectives within the national hierarchy of operations and thus the required spectrum of military missions including OOTW capabilities;
- Explicitly identify and describe the scenarios prior to the execution of a study. However, it might be necessary to revisit the scenario definition during the conduct of the study;
- Information and hypotheses on threats, adversary forces, and non-combatants should be addressed in the scenario;
- Explicitly identify the C2 aspects under consideration within the problem definition; and
- During the analysis, the key scenario assumptions should be identified and documented.

Challenges

- Standards for judging the applicability and accreditation of (existing) models should be developed; and
- For coalition C2 assessments the scenarios should be developed or adapted by teams including representatives from all participating nations.

Chapter 7 Acronyms

C2 – Command and Control

CCIS – Command and Control Information Systems

COBP – Code of Best Practice

IO – International Organisation

MoFE – Measures of Force Effectiveness

MoM – Measures of Merit

MoPE – Measures of Policy Effectiveness

NGO – Non-Government Organisation

OA – Operational Analysis

STA – Surveillance Targeting and Acquisition

VV&A – Verification, Validation, and Accreditation

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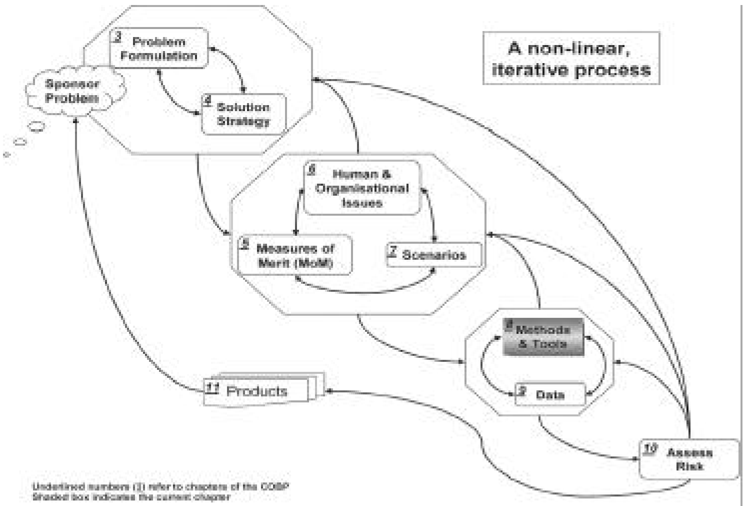
CHAPTER 8

Methods and Tools



The reasonable course of action in any use of arms starts with calculation. Before fighting, first assess the relative sagacity of the military leadership, the relative strength of the enemy, the size of the armies, the lie of the land, and the adequacy of provisions. If you send troops out only after making these calculations, you will never fail to win.

—Liu Ji, 1310-1375, *Lessons of War*

War is essentially a calculation of probabilities.

—Napoleon

If the only tool that you have is a hammer, you tend to see every problem as a nail.

—attributed to a Harvard anthropologist

The purpose of this chapter is to consider the best methods for representing Command and Control (C2) systems, processes, organisations, and their interaction in order to support assessments of C2 over the full spectrum of operations, to include Operations Other Than War (OOTW). The key objective is to establish an 'audit trail' from data or information collected, through its processing, presentation, dissemination, and use to the performance of C2 processes and organisation as well as to high-level measures of their effects on battle or operations outcome.

This chapter of the revised COBP extends the code to cover method and tool considerations regarding OOTW. The material in this chapter is a distillation of the best approaches and ideas being considered in current NATO research for representing C2 across the full spectrum of operations in all models/tools.

Types of Methods and Tools

This chapter covers all tools (simulations or other quantitative or qualitative techniques), whether used for analysis, training, or operational purposes that can be used to assess C2 processes, performance, and effectiveness. Available methods and tools can be categorised into four distinct groups:

- Data collection/generation: methods and tools used to either collect or generate subjective or objective data for subsequent analysis from live, virtual, or constructive sources, whether past, present, or future;

- Data organisation/relationship: methods and tools used to organise data in some logical way, or used to establish relationships between data. These methods and tools, rather than providing a mathematical solution to problems, tend to be more qualitative, subjective, and exploratory techniques based on expert opinion, judgement, and interaction, whether obtained directly or through role playing. Although, in some cases, these tools/techniques may totally solve the problem at hand, more often they will illuminate other associated or sub-problems, determine areas for further analysis, or provide expert input "data" for more quantitative "solving" tools;

- Solving: methods and tools which have been typically associated with operations research, business, mathematics, computer science, information science, engineering, or management science which tend to be quantitative in nature and which usually consist of techniques providing mathematically derived solutions, even if the data analysed is subjective in nature; and

- Support: methods and tools used to collect, organise, store, and explore typically large sets of empirical data.

Table 8.1 provides some recommended methods and tools that fall into each category. The intent here is not to provide an exhaustive list or to debate into which category a specific method or tool should be included, but to give the range of methods and tools available to the analyst for C2 assessment. While the range and scope of potential methods and tools is broad, clearly the emphasis of this chapter of the COBP, and of the analysis community at large over recent years, is on constructive modelling and how best to enhance, orchestrate, and apply it to the assessment of C2 impacts on battle/operations outcome.

	Data Generation	Data Collection	Data Organization/ Relationship	"Solving"	Support
Real World Operations	•				
After Action Reviews		•	•		
Historical Analysis		•	•		
Expert Elicitation		•			
Constructive Simulations	•	•	•		
Virtual Simulations	•	•	•		
Exercises	•		•		
Experiments/ Experimental Design	•		•		
Game Theory			•	•	
Army C2 Evaluation System (ACCES)		•	•		
Headquarters Effectiveness Assessment Tool (HEAT)		•	•		
Causal Mapping			•		
Multi-Criteria Decision Analysis (MCDA)			•	•	
Regression Analysis			•	•	
Factor Analysis			•	•	
Bayesian Networks			•	•	
Neural Networks			•	•	
Systematic Approaches			•	•	
Mathematical Programming			•	•	
Heuristic Search				•	
Genetic Algorithms	•			•	
Project Management Tools					•
Data Analysis			•		
Geographical Information Systems		•			
Visualization	•				•
Databases			•		•
Checklists		•			
Spreadsheets			•		

Table 8.1. Some Recommended Tools by Category Type

Issues

The NATO analytic community has had many challenges in the past analysing the effectiveness of C2 related systems and determining what it is that sets it apart from other types of operational analysis. The added complexity and number of confounded variables in OOTW make analysis of these operations even more challenging. The key to the problem, no matter where on the spectrum of conflict the analysis is located, lies in making a properly quantified linkage between C2 Measures of Performance (MoP), such as communication system delays, C2 Measures of Measures of C2 Effectiveness (MoCE), such as planning time, and their resultant impact on higher level Measures of Force Effectiveness (MoFE) or Measures of Policy Effectiveness (MoPE), which capture the effects on battle or operations outcome. These higher level MoFE/MoPE are required in order to be able to trade off investment in C2 systems against investment in combat systems such as tanks or aircraft. At present, there is no routine way of making this linkage, nor any one tool that can be applied to generate the required measures. Hence, all analyses of C2 issues demand a high level of creative problem structuring and approach, and selection and application of a range of available analysis tools, to overcome this challenge.

The range of issues is very broad and challenging. Particularly challenging are the following issues that will be addressed in more detail later in this chapter:

- Representation of human behaviour (e.g. rule-based, algorithmic, or "human-in-the- loop");
- Homogeneous models versus hierarchies/ federations;

- Stochastic versus deterministic models;
- Adversarial representation;
- Verification, Validation, and Accreditation (VV&A); and
- The conduct of sensitivity analysis and other ways of dealing with uncertainty.

Of particular importance for analysis of OOTW:

- Selecting an orchestrated set of tools that generate the required MoM;
- Scoping the analysis considering tool availability;
- Considering the human dimension in tool selection early in the process; and
- Ensuring tools selected have the trust and confidence of the decisionmaker(s).

Representation of Human Behaviour: Rule-Based, Algorithmic, or "Human-in-the Loop"

In developing methods and tools that represent the process and performance of C2 explicitly, most approaches until very recently have been founded on the artificial intelligence (AI) methods of expert systems. These represent the commander's decisionmaking process (at any given level of command) by a set of interacting decision rules. The advantage of such an approach is that it is based on sound AI principles. However, in practice it leads to tools which are large, complex, and slow. The decision rules themselves are, in many cases, very scenario dependent and, as noted in Chapter 6 – Human Decisionmaking, human factors and organisational expertise may be needed on a project team to treat these issues correctly.

These factors were not a problem when the Cold War prevailed. There was sufficient time to complete extended analyses, and one key scenario dominated. However, in the post-Cold War environment, such certainties have evaporated. Indeed, uncertainty is now one of the key drivers of analysis. There is an increasing requirement to consider large numbers of scenarios and to perform a wide range of sensitivity analyses. This has led to a requirement for 'lightweight,' fast running tools, that can easily explore a wide range of scenarios, yet still appropriately represent C2. Some have begun to explore advanced algorithmic tools based on Bayesian mathematics, catastrophe theory, and complexity theory. Such approaches to the representation of C2 are at the core of a new generation of closed form constructive simulation models that are beginning to be used for analysis. (Moffat, 2002; Moffat, 2000).

Many analyses employ "human-in-the-loop" techniques in order to ensure realistic human performance or to check assumptions and parameters. However, "human-in-the-loop" techniques are expensive and require the inclusion of soft factors and their attendant MoM. The introduction of "human-in-the loop" introduces a source of variances and uncertainty. The increased cost, complexity, and uncertainty of "human-in-the-loop" methods often requires analysts to limit the use of these techniques rather than employ them as the primary analytical method.

Homogeneous Model-Tools versus Hierarchies/Federations

In order to build an "audit trail" that traces the interrelationships among individual C2 systems, processes, and organisations, as well as their impacts on mission operational outcomes, there is a need to represent the key detailed processes involved, such as the transmission of communications across the battlefield and the impact of logistics on decisionmaking. Taking this as an example, the question then arises as to whether all the transmission media (radio, satellites, etc.), with their capacities, security level, communications protocols, etc., should be represented explicitly, or whether these details should be split out in a supporting model. Similarly, the details of logistics could be undertaken as part of the main model or in a specialised supporting model. Supporting models could be run off-line, providing sets of input data to the main model (giving rise to a model hierarchy) or they could be run in real time interaction with the main model (giving rise to a model federation). In the off-line mode, the main model would generate demands on the communications and logistics systems. The supporting models would check if these demands could be satisfied. If not, communication delays and logistics constraints in the main model would be increased, and the main model re-run. This would have to be done a number of times to bring the main and supporting models into balance. However, such an approach can generate valuable analytical insights.

Figure 8.1 shows the main model-tool producing (in addition to its MoFE) a detailed set of dynamic demands on the communications (such as capacity required of different communications systems as a function of simulated time), and logistics processes (demands for transport and key consumables), in order to achieve the assessed levels of MoFE. These are then fed back into detailed model-tools of the communications and logistics infrastructure. Those supporting model-tools can then be matched against the dynamic demand placed on the communications and logistics infrastructure to the available capacity. If there is a mismatch, the assumptions in the main model-tools are adjusted iteratively to bring the two model-tools into balance. This approach is more flexible and reactive for a large set of C2 assessments. However, this approach increases the complexity of the architecture (number of linked sub-processes, failure of the sub-model, etc.)

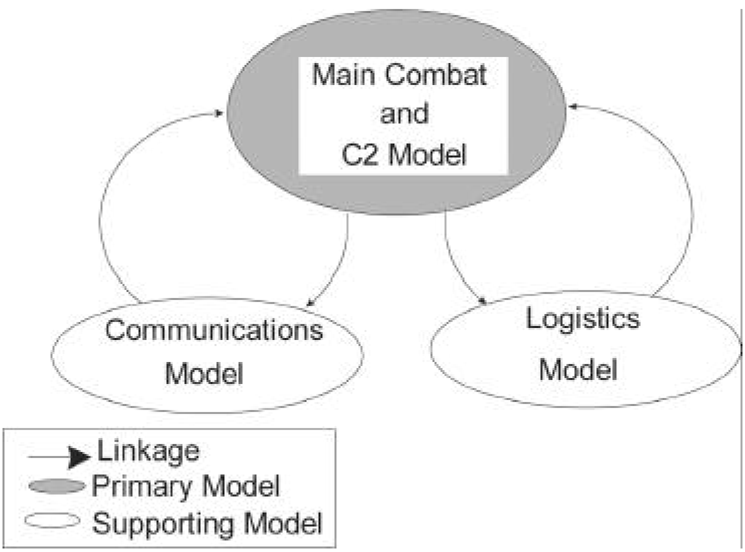


Figure 8.1. Model Linkage

A similar approach can be applied to concepts of operation. In some models, it is possible to describe a concept of operations as a sequence of standard missions (e.g. attack, defend, move). These missions can then be analysed to determine the demands they place on the supporting infrastructures. This can be tested off-line to see if the infrastructure can cope. Again, this would have to be iterated a number of times, but provides an ability to relate, in an understandable way, the infrastructure capacity to its ability to support a defined concept of operations (and hence battle outcome). In addition to the use of such hierarchies of supporting models in an off-line mode, it is possible to create real-time federations of such models to represent, inter alia, combined or joint operations.

Stochastic versus Deterministic Models

Stochastic and deterministic models differ in how they treat variables. Stochastic models incorporate the attributes of the probability density (or distribution) functions associated with model variable into run time calculations. The actual values of model variables will therefore differ each time the model is run. Thus, the output of a stochastic model will yield different results each time even when a set of inputs is "fixed." Deterministic models utilise point estimates for the values of model variables, and hence for any given set of inputs the model will produce a single output.

Stochastic and deterministic models each have their advantages. The selection of which to use or how to employ each type of model in an assessment depends upon the nature of the problem and other elements of the solution approach. Whether the model is time step driven or event sequence driven will also impact on the selection of the appropriate models(s).

Deterministic Models

The merits of a deterministic approach are that run-times are reduced, and there is a single 'thread' connecting the input data and the results, making the analysis of the tool output potentially easier. The justification for using deterministic (expected value) tools is usually based on the assumption that, due to the large number of stochastic processes involved in combat on higher levels, their results converge rather quickly to the mean values obtained from stochastic models.

Stochastic Models

Stochastic models do provide significantly more information than deterministic tools. They are deemed to be indispensable for an assessment of the robustness of the results as well as providing the "data" needed for risk analysis. These additional benefits come at the cost of significantly higher run time requirements and a more complex analysis task.

Chaos theory shows that structural variance (or 'deterministic chaos') can occur when sets of decision rules interact in the simulation of a dynamic process. Small changes in initial conditions can lead to very different trajectories of system evolution. Any simulation model of combat, with a representation of C2, has to face this kind of problem. The merits of a deterministic approach are that run times are reduced and there is a single 'thread' connecting the input data and the results, making analysis of the model output potentially easier. However, the representation of the C2 process (whether using decision rules or not) gives rise to a number of alternative decision options at any given moment, and can thus potentially give rise to such ‘deterministic chaos’. If such effects are likely to arise, one solution is to use stochastic modelling. The use of stochastic sampling in the model, together with multiple replications of the model, gives rise to a distribution of outcomes, which is much more resistant to such chaotic effects.

US Army Training And Doctrine Command (TRADOC) has been experimenting with Deterministic Combat Models. “A potential alternative solution, when the issue under study warrants, is to conduct analysis of multiple runs of a deterministic model where the initial states of information systems are varied.” (Bailey, 2001).

Representing Adversary Forces

Historically, adversary capabilities and behaviours were often fully scripted or heavily constrained. This was more appropriate in Cold War contexts than it is today. However, it was never ideal for C2 analysis because the dynamic interaction among friendly, adversary, and other forces is a critical element of C2 representation. Today, much more robust adversary representation of operational capabilities and choices are employed and indeed are necessary. Analysts must consider not only a range of scenarios, but also the range of possible adversary actions and reactions.

Verification, Validation, and Accreditation (VV&A)

VV&A has historically been a challenge for model development efforts, but is particularly challenging for C2 modelling. This is due to the variability inherent in most C2 processes, especially those that involve the human aspects of information processing and decisionmaking. The approach to VV&A needs to be carefully considered, particularly in light of the need to assess future C2 systems and capabilities in association with new concepts of operation, new organisational forms, new doctrine and asymmetrical adversaries.

Selecting an Orchestrated Set of Tools

The natural tendency of an analyst is to simplify a problem. Part of that simplification is to select a tool, preferably only one, which will meet the analysis requirements. In the analysis of C2 of combat operations, this may be possible if the analysis is properly scoped. In the analysis of OOTW C2, the issues are typically too numerous, the variables too confounding and the scope too broad for one tool to satisfy all analysis requirements. An orchestrated set of complementary tools will normally be required.

Scoping the Analysis Considering Tool Availability

An analyst must always scope the analysis during problem formulation to enable it to be accomplished within available resource constraints. During problem formulation, however, the consideration of available tools has typically not been a driving factor. Also, in the analysis of C2 combat operations this may not be a problem because selection of the tool(s) to be used is more obvious based on past experience. However, for OOTW C2 analysis, the availability of tools, and their orchestration, requires more consideration early in the process (i.e. during problem formulation).

Consideration of the Human Dimension

C2, by its very nature, is closely linked to human behaviour, and its analysis requires careful consideration and inclusion of the human dimension. Often, as a way of simplifying the analysis, the C2 assessment team eliminates these considerations by assuming that human commanders and their staffs are not affected by their environment and will always make the best decision, and the same decision, given the required information. This is unsafe and not good practice. This has been especially true for the analysis of OOTW C2, even though this analysis is often more impacted by the human dimension than C2 for combat operations.

Ensuring Trust and Confidence in the Tools

Analysts select and apply the tools of their trade based on what those tools can do for them in accomplishing their analysis objectives. Over time they become comfortable with certain tools and the customers for their analysis also develop a trust in the tools and confidence that they will produce valid results for them. For OOTW C2 analysis, given that the tools are more numerous, must be orchestrated to work together, and are sometimes unknown or not understood by the customer, the development of trust and confidence in these tools is difficult to achieve.

New Methods and Emerging Practices

Given the inherent problems associated with the issues described previously, a best practice for the application of analysis tools for C2 analysis is still emerging. This best practice is described below, first for tools in general, then for models, both at the model level itself and at the algorithm level.

Selection of Methods and Tools

The selection of tools to apply to C2 analysis should be based both on evaluation of the candidate tools themselves against a set of evaluation criteria and on consideration of the type of study to be undertaken. The evaluation criteria for tool selection includes criteria related to the functionality of the candidate tool and to the performance of the candidate tool. The following are established evaluation criteria for tool selection. They are as applicable to tool selection for OOTW C2 as for combat C2 analysis.

- Functionality-related tool selection criteria:
    - Resolution: the level of detail in representation of entities within the tool;
    - Completeness/scope: the extent to which the tool is able to address analysis issues;
    - Functionality: the extent to which the tool represents the full range of functions;

- Explicitness: the ability of the tool to explicitly represent required entities;
- MoM Generation: the ability of the tool to generate the MoM required;
- VV&A: the determination of whether the tool has been verified, validated, and/or accredited for it intended use; (Note: Not all NATO member nations recognise the term “Accreditation.” Accreditation here refers to some form of formal approval to use the model for the analysis intended.)

• Performance-related tool selection criteria:

- Responsiveness: the amount of time between request and receipt of information;
- Simplicity: the ease of preparation and use the tools;
- Preparation/use time: the length of time necessary to prepare and use the tool;
- Data availability and parameters: the ease in acquiring or generating the necessary data or parameters for tool use;
- Interoperability: the ability of the tool to interoperate with other tools;
- Resource requirements: the amount of resources (time, personnel, and funds) required; and
- Credibility: the extent to which the customers and users accept tool results.

Using Models

The potential for exploiting recent advances in mathematics in order to create fast running model-tools was noted earlier. Such models have exploited emerging approaches, such as complexity theory, chaos theory, catastrophe theory, and game theory in order to produce a 'good enough' representation. They can be used to complement more complex, detailed models of the problem area. In many cases, a tailoring of models, or other tools, will be required to properly address the analysis issues at hand. (Moffat, 2002; Moffat, 2000).

Model Federations

A number of new approaches share a key set of characteristics. First, an object-oriented approach within the model-tool allows different objects to be brought together to represent the complete command process, rather like 'Lego™ bricks.' Such a philosophy also encourages the development of model-tools based on holistic and evolutionary principles. In other words, always capture a complete model of the process, including the parts whose representation is still unclear. As understanding develops, improve those parts (or objects) which were rudimentary at the start. At the next level up, the use of run-time interfacing allows different model-tools to be brought together to create a federation to represent the process under study. This federation then may also have to be integrated with the use of a mix of tools, which include techniques other than modelling, to fully address the study issues.

Agent-Oriented Modelling

A second key aspect is the description and representation of the C2 process through agent modelling and programming techniques. Modelling of the C2 process as a group of agents, based on artificial intelligence concepts, favours the capture of the cognitive nature of command tasks. Agents can be implemented, in an object-oriented environment, as either objects (e.g., actor or "applet" type of agents), or aggregates of objects (coarse-grain agents). Such agents interact with each other through a messaging infrastructure. The term "agent-oriented modelling" is suggested as a way of capturing this idea.

Linking of Performance Model-Tools to Effectiveness Tools

This third idea, used in a number of NATO countries, uses a structured hierarchy of model-tools to create an audit trail from C2 systems, processes, and organisations through to battle operations outcome. The idea is to create supporting performance level model-tools of particular aspects of the process (e.g., communications, logistics) which can be examined at the performance level. These then form inputs to higher level force on force models. This ensures that the combat models themselves do not become overly complex. We have already discussed this in the sense of hierarchies of support models.

For example, in Figure 8.2, a detailed model of the intelligence system can be very complex, if we wish to take account flow of intelligence requirements, tasking, collection processes, fusion processes, and intelligence products. In order to analyse the impact of intelligence, it is important to have all of this detail, but it does not necessarily have to be represented explicitly in the main model. A supporting model-tool which captures all of this detail can be created (or used if one already exists) in order to produce outputs at the MoCE level, such as speed and quality of intelligence. These can then form inputs to the main simulation model. The main model-tool then takes these into account in producing its own outputs. These will now be at the MoFE level. Examples are friendly casualty levels, adversary attrition, and time to achieve military objectives.

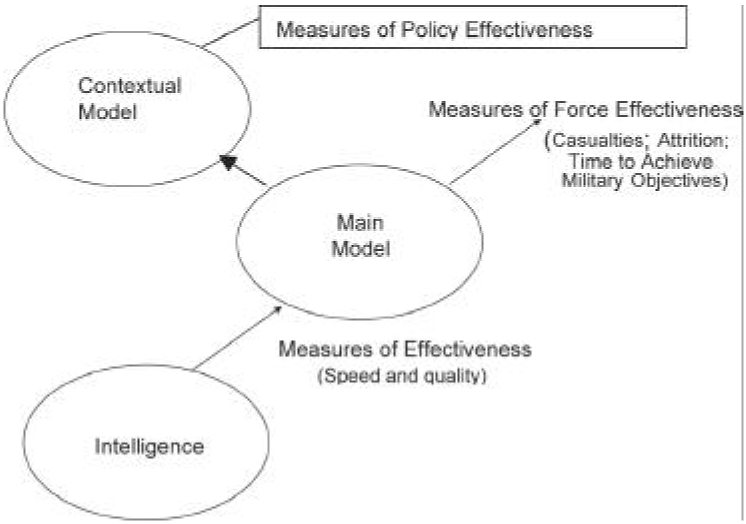


Figure 8.2. Model-Tool Hierarchy

Scanning Scenario Space

The use of very fast model-tools to scan the overall space of possibilities and to identify areas of concern for further analysis appears to give a good balance between the use of simple and complex modelling approaches. Fast models, which are simpler but may have less analytic depth, allow the analyst to scope the problem and determine the degree of complexity a model-tool must represent in order to conduct the desired level of analysis.

Decisionmaking Process

It is important to have a proper representation of the decisionmaking process in order to establish the link from C2 performance through MoE to overall MoFE and to represent information operations (IO) effects such as Counter C2 or digitisation of the battlespace. Representation of the decisionmaking process itself, however, remains difficult because of the difficulty in representing human performance, command styles, and organisational relationships.

Parameter Development Context

Finally, it may become necessary to generate new or additional data to validate new or existing model-tools to incorporate C2 factors. This may be especially true in the case of integrating soft factors into C2 analysis. Possible methods include field trials, “model-test-model”, or advanced warfighting experiments. Field trials are used if uncertainty revolves around measurable factors that are only observable in the field or are not reproducible in the laboratory. Model-Test-Model (M-T-M) or Model-Exercise-Model (M-E-M) is used as part of an iterative process to develop and apply systematically more in-depth and sophisticated model-tools and, in some cases, more simplistic model-tools to increase their validity. The original model-tool is executed, modified based on results of the test or experiment, and executed again until it has developed a sufficient representation of a complex process. Experiments, like advanced warfighting experiments, are useful in modelling new, large scale, and complex interactions for which little data or few validated tools exist. Each approach requires additional time and resources, and the data sets may not be validated for some time.

C2 Modelling Guidelines

A number of common ideas have emerged which are worth consideration for new modelling and tool developments. Figure 8.3 shows how each of the following common ideas are represented within an ideal command and control model:

- Understanding of adversary intent can be represented by having a number of prescribed intents or options, which are updated in an advanced data architecture, or Bayesian way, as more information becomes available;
- Representing headquarters explicitly in the model-tool allows proper representation of Information Warfare (IW) effects such as counter C2;
- Explicit representation of the "recognised picture" within each headquarters (HQ) allows the model-tool to run based on different perceptions by each individual unit on each side represented. This allows the effects of aspects such as deception, shock, and surprise to be explicitly considered;
- Represent information as a commodity. This consideration is the most critical and difficult to

implement, but is the foundation for the other guidelines, as well as for the model itself. Information should be considered as a resource that can be collected, processed, and disseminated. It includes information about adversary, friendly, and other forces, considerations such as political-military factors and rules of engagement (ROE), as well as environmental information such as weather and terrain. Information should posses dynamic values such as accuracy, relevance, timeliness, completeness, and precision. These values should in some way affect other activities within the model, to include, when appropriate, combat functions;

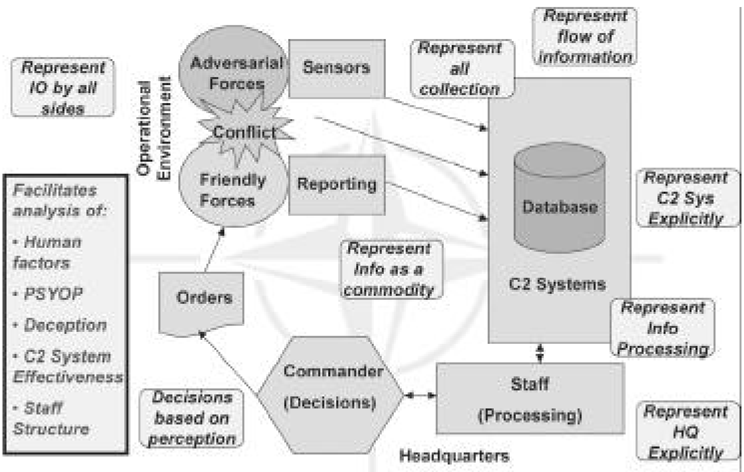


Figure 8.3. Modelling Guidelines

- Represent the realistic flow of information throughout the operational environment. Information has a specific source, and that source is usually not the end user of the information. A requirement exists, therefore, to move information from one place to another in the operational environment. Communications systems of all forms exist to accomplish this movement. These systems can be analogue or digital. Information can be lost and/or degraded as it flows around the operational environment. The model-tool should represent the communications systems and account for these degradation factors as it represents information flow;

- Represent the collection of information from multiple sources and tasking of information collection assets. This guideline applies equally to adversary, neutral, and friendly and other force information. For the collection of adversary and other force information, the model-tool should represent a full suite of sensors and information collection systems, and the ability of these systems to be tasked to collect specific information. For the collection of friendly information, this consideration is just as critical. Knowledge of one's own capability in combat, as well as that of the adversary and other forces, is essential for effective decisionmaking;

- Represent the processing of information. Information is rarely valuable in its original form. It usually has to be processed in some way. Typical processing requirements include filtering, correlation, aggregation, disaggregation, and fusion of information. These processes can be accomplished by either manual or automated means. The ability, or inability, to properly process information, and the time it takes can have a direct bearing on combat operational outcome;

- Represent C2 systems as entities in the operational environment. C2 systems perform information collection, processing, dissemination, and display functions. They should be explicitly represented as entities that can be targeted, degraded, and/or destroyed by either physical or non-physical means. Additionally, the model-tool should account for continuity of operations of critical functions during periods of system failure or degradation;

- Represent unit perceptions built, updated, and validated from the information available to the unit from its information systems. This is a critical requirement. Each unit should have its own perceptions, gaining knowledge from superior, subordinate, or adjacent units only when appropriate;

- Represent commander's decisions based on the unit's perception of the battlefield. Each unit should act based on what it perceives the situation to be informed by its commander's intent of mission, goals, constraints, and biases, not based on ground truth available within the model. When a unit takes action based on inaccurate perceptions, it should suffer the appropriate consequences; and

- Represent IO for each/all combatants. With information so critical to combat operations outcome, the model-tool should be able to represent the deliberate attack and protection of information, information systems, and decisions. This applies to all sides represented in the model.

As shown in Figure 8.3, explicit representation of these information operations elements within a command and control will facilitate the assessment of human factors, psychological operations, deception, C2 systems effectiveness, and staff structure issues.

Conclusions

The following conclusions are made regarding the strengths and weaknesses of current C2 tools/ modelling approaches.

Strengths in Current C2 Tools/Modelling

An assessment of current C2 modelling approaches employed against the guidelines above show that, while they may not yet be satisfied, there are some strengths in the C2 tools/modelling approaches currently being implemented:

- There is a common understanding of issues. This has not always been the case. With the inherent complexity of C2, as well as the challenges in modelling such a complex subject, there has been a tendency in the past to ignore the subject, or just to accept it as something that is too complex to address. This does not seem to be the case now. Perhaps through the emergence of new technologies and through the work of groups such as the NATO SAS groups, the analysis and modelling of C2 is now considered possible. Member nations now seem to have both an understanding of C2 and its importance to combat and OOTW operations and a common understanding of the modelling challenges that exist.

- There is wide application of C2 modelling. Member nations now apply C2 modelling and analysis to a wide range of issues. These issues include those associated with investment, requirement identification, force structuring and operational support. In all of these areas, there is understanding of the sensitivity and criticality of C2 to the proper analysis of combat operations outcome. Selection of the model-tools to apply to a particular problem should be based on evaluation of specific criteria, as discussed previously in this chapter.
- Although each nation develops its models for different purposes and tailors their models and other tools for specific issues, there exists a commonality of approaches in different nations that serves to strengthen their collective merits. These common approaches are an outgrowth of the modelling technologies now available, but also result from shared experiences by member nations.
- Most of the progress and success in C2 modelling has been with regard to high-intensity combat. This is perhaps due to the belief by many that a high-intensity combat scenario is still most appropriate for the analysis of combat, particularly for analysis of primary combat systems. Progress, therefore, has been focused on embellishing high-intensity combat analysis with C2 improvements to models. Unfortunately, low-intensity combat and OOTW modelling and

analysis have not received the same level of attention until recently.

- There is wide use of evolutionary development approaches. After many years of neglect, a problem as complex and difficult as C2 modelling requires years of focused research and development. There are no simple fixes to the problem. It is evident that member nations recognise this and are willing to approach the problem in an incremental manner, applying evolutionary approaches.

- There is progress in linking and federating models. Significant progress has been made by several nations in linking performance model-tools with combat effectiveness models, either directly or through off-line approaches. Additionally, creating federations of models through standard interface protocols has significantly improved the use, and reuse, of existing models and has provided a promising approach for future modelling. The inherent difficulties in federating models, given today's state of the art, must be considered when contemplating this approach.

- There is progress in modelling "soft factors." Several nations have made real progress in modelling phenomena that have non-physical, or soft impact, on combat operations outcome. Among these factors are morale, fatigue, and training proficiency. These and other soft factors have increased importance on combat operations outcome as C2 modelling improves combat models.

- Standard interface protocols, data standards, and other standards either now exist, or are under development. These standards serve to make this difficult task easier. Continued development of such standards is envisioned for the future is essential.
- There is widespread use of Commercial Off The Shelf (COTS) products. These products are generally available to all member nations. This use of COTS has served to help further standardise individual modelling approaches and will continue to do so in the future.
- There is application of new information technologies. New technologies, such as those supporting animation, have been applied to the challenge of C2 modelling simulation, and analysis. Additional technological advancements will no doubt continue and will be similarly applied to this problem.

Weaknesses in Current C2 Tools/Modelling

An assessment of current C2 modelling approaches employed against the guidelines above show that weaknesses exist in current approaches. These weaknesses, rather than being enumerated here, are expressed as challenges below.

Recommendations

It is recommended that analysts take advantage of the strengths available in current approaches and in the new methods that are evolving. They should also be aware of the challenges that must still be resolved and should attempt to play their part in helping address those challenges both through study activities and research.

Challenges: OOTW

As discussed previously, recent world events and current projections call for an emphasis on OOTW. C2 in these environments can be quite different and may require fresh C2 tool/modelling approaches to link C2 to outcome in these environments. The following challenges with tools-models for C2 Assessment exist:

- Orchestrating a set of applicable tools. Because there is no one universally accepted tool that will satisfy OOTW C2 analysis requirements, a set of tools must be selected, based on evaluation of potential tools against selection criteria, and applied to the analysis. Orchestrating a set of tools that complement the strengths and weaknesses of each to satisfy the analysis requirements is difficult. Proper consideration of assumptions and constraints during tool selection, and careful scoping the analysis issues, will help to simplify the orchestration of tools. Additionally, it must be remembered that not only the tools, but trained, skilled users of the tools are required.

- Breadth of tool application. Because of the complexity of OOTW analysis, the full set of potential tools should be considered for application throughout the study process, from problem formulation through sensitivity analysis. Additionally, the more subjective nature of OOTW dictates that tools, heretofore not typically applied to the analysis of C2, be considered for use throughout the study process.

- Relationship of tools to data availability and MoM generation. Tools must be selected for OOTW C2 analysis that have necessary data available, or able to be generated or obtained from the application of other tools. Reliance on more subjective data, especially for higher C2 echelons, may be necessary. Additionally, tools must be selected that generate the MoMs that will help answer the study issues at hand. The OOTW C2 analyst will be challenged to be creative in establishing the strong relationship between data, tools, and MoM required for a successful OOTW C2 analysis. It must be remembered that analysts, not the tools themselves, answer the analysis issues.

- Consideration of M-E-M or M-T-M. Capitalisation on testing or training events for C2 analysis purposes can be highly beneficial, both from a resource and analytic point of view, but doing so can be difficult. Such approaches are more subjective, take more human involvement, and are inherently more complex than more classical analysis tools/approaches. The advantages of having live players/subjects in the analysis, however, generally outweigh the disadvantages. These approaches are becoming more commonplace and more accepted as a legitimate analysis approach, especially for more subjective issues such as those associated with OOTW C2.

- Sharing of tools between different communities. Given the nature of analysis of OOTW C2 and the emergence of M-E-M and M-T-M approaches, the boundaries between the testing, training, analytic, and operational communities are blurring and tools once considered for use in only one of these communities are finding application in another. The sharing of available tools among these communities is considered even more appropriate now with the rise in importance of complex OOTW C2 analysis requirements. This sharing, however, is difficult due to differences in terminology, as well as cultural differences between the different communities.

- Reuse of operational schemas and data models. OOTW typically involves many more organisational entities than combat operations, making interoperability of organisations and systems critical to successful operations. C2 analysts, therefore, are challenged to ensure they use, to the extent possible, existing operational schemas, such as orders and reports, and data models used for C3I systems integration, whenever possible to further standardization and interoperability goals.

- Analysis of architectures. Technical, operational, and system architectures are sometimes developed in order to facilitate integration and interoperability of C3I systems. For NATO, required architecture frameworks are contained in the NATO C3 Interoperability Management Plan (NIMP), Volume II. Considerable challenges exist in developing and applying analytic tools for evaluation architectures, to include analysis of alternative architectures and their implications.

- Management of customer expectations and relations. OOTW C2 analysis is so difficult that it is necessary for the analyst to ensure the customer for the analysis understands the inherent difficulty and to attempt to manage the customer expectations for the analysis. This includes informing the customer of the tools to be employed and to gain an understanding and trust in those tools by the customer. It also implies a special relationship between analyst and customer for OOTW C2 analysis. This is even more critical when the customer is a subject of the analysis, such as when a commander has his/her own command analysed.

Challenges: Modelling C2

The following challenges with modelling C2 exist:

- Better representation of cognitive processes. C2 can be incorporated at one level of resolution in combat tools through representation of the effects of particular decisions. At another level, representation of the decision process itself is desirable. It would enable alternative decisionmaking styles and the effects of soft factors such as stress, training level, fatigue, and morale to be more easily assessed. These factors become more important as the full range of IO representation is attempted;

- Long standing challenges associated with both stochastic and deterministic models. The advantages and disadvantages associated with stochastic and deterministic modelling approaches will remain as C2 modelling improves. The objective is to select the best modelling approach for the issue at hand. Recognising the inherent advantages and disadvantages, and then capitalising on the advantages while minimising the disadvantages, are the challenges;

- Better standard definition of C2 terms. This challenge has plagued the C2 community for many years, because of both the scope and complexity of the subject. This is particularly true across service boundaries and across the international community. A standard set of definitions would greatly simplify the C2 modelling challenge;
- The definition and application of C2 scope. This challenge, related to the previous challenge, is especially critical to modellers. The C2 of a fighter aircraft or a carrier group is very different from the C2 of an army corps or an army squad. On the other hand, there are C2 aspects of each of these combat elements that are similar. Modelling of C2, however, can be vastly different in each case. The scope of each modelling undertaking must be properly considered and discipline must be applied throughout model development to focus on the proper scope. Once the scope is established, a mix of tools may be required to address the full scope of the analysis;
- Multiple application of C2 model-tools to analysis, training, and operational requirements. C2

phenomena are relatively constant whether they exist within the analytic, training, or operational environment, and they should be consistently modelled in each environment. This fact, as well as the obvious need to conserve expensive model-tool development resources wherever possible, leads to the challenge of developing C2 models, or at least component software modules that can be used to support analysis, training, and operational requirements;

- Level of resource application to the breadth and depth of C2 modelling. Because of the large scope of C2, there has been a tendency by some to model C2 at great breadth (multiple applications), at the expense of modelling C2 phenomena at a corresponding depth. In a constrained resource world, sufficient resources are not usually available for both. The challenge is to either apply sufficient resources or to recognise the shortfall and to level the available resources across the breadth and depth of the problem. Models and other tools must, therefore, be tailored to the extent possible to fit the study issues being addressed;

- Differences in the level of modelling of friendly and adversary forces. Many combat models do not represent adversary forces to the same level of resolution as friendly forces. In the past, there may have been good reasons for this. Besides the obvious resource savings, the lack of C2 representation often precluded further representation of adversary forces. Valid representation of C2, to include full play of IO such as deception and psychological operations, will require equal representation across both adversary and friendly forces, as well as any other supporting or neutral forces in the simulation. All discussion and recommendations in the COBP, therefore, are equally applicable to modelling of adversary forces as it is to modelling friendly force C2. This represents a significant challenge to many modelling efforts;

- Continuing lack of "soft factor" representation and data. As discussed previously, a robust C2 representation in combat models will permit soft factors to be better represented. The bigger challenge, perhaps, may not be the modelling methodology itself, but the acquisition of data to support it. The effects of such things as stress, training proficiency, morale, fatigue, and shock, for example, necessitate new data generation approaches, which will take some years to implement. The tasks of VV&A and Verification, Validation, and Certification (VV&C) are most severe in their soft factor arena. The certification of soft factor data, as well as most all C2-related data, is particularly difficult to achieve. Innovative and focused C2 data VV&C programs are required;

- VV&A of C2 model-tools and the parameters that drive them. This is always a challenge for model-tool development efforts, but is particularly challenging for C2 modelling, due to the variability inherent in most C2 processes, especially those that involve the human aspects of information processing and decisionmaking; and

- Sensitivity Analysis. The challenges associated with the proper conduct of sensitivity analysis of C2 is as great as, or perhaps greater than, that associated with other analyses. This is because of the uncertainty associated with C2 itself, and the relatively immature modelling of C2 that exists today. Innovative, yet cost-effective approaches to sensitivity analysis are required.

Chapter 8 Acronyms

ACCESS – Army Command and Control Evaluation System

AI – Artificial Intelligence

C2 – Command and Control

CPX – Command Post Exercise

FTX – Field Post Exercise

HEAT – Headquarters Effectiveness Assessment System

HQ – Headquarters

MAPEX – Map Exercise

M-E-M – Model-Exercise-Model

MoCE – Measures of C2 Effectiveness

MoFE – Measures of Force Effectiveness

MoP – Measures of Performance

MoPE – Measures of Policy Effectiveness

M-T-M – Model-Test-Model

ROE – Rules of Engagement

OOTW – Operations Other Than War

STAFFEX – Staff Exercise

TRADOC – US Army Training And Doctrine Command

VV&A – Verification, Validation, and Accreditation

VV&C – Verification, Validation, & Certification

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This chapter is based in part on the results of previous workshops on models used for C3I systems and analyses. Additional Useful references include:

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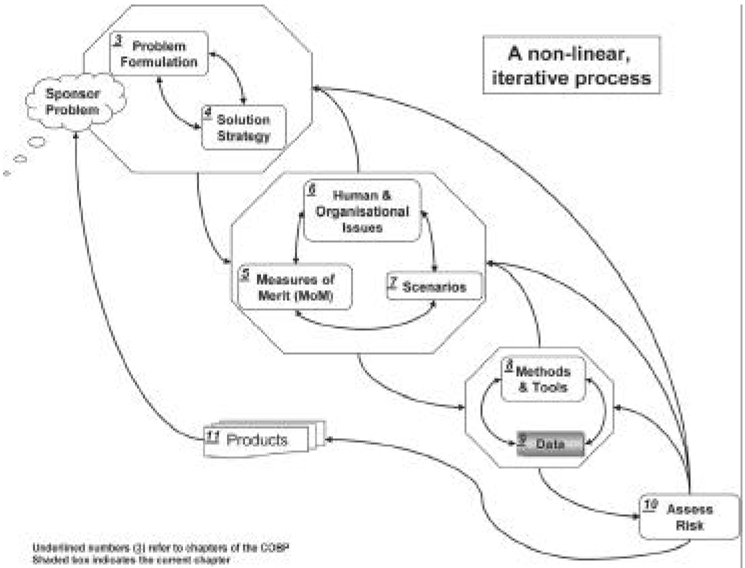
CHAPTER 9

Data



Know the enemy and know yourself; in a hundred battles you will never be in peril. When you are ignorant of the enemy but know yourself, your chances of winning or losing are equal. If ignorant both of your enemy and of yourself, you are certain in every battle to be in peril.

—Sun Tzu, *The Art of War*

Definitions

Data are factual information that are organised for analysis and in a form suitable for machine processing. Data are usually thought of as anchoring an epistemological scale with understanding or wisdom anchoring the other end. Information is data that have been put into context.

Metadata are "information about information." Metadata can describe data as well as metadata, therefore there are several levels of metadata possible. An example for metadata on a higher level is the reliability of the source that data have been derived from. In general, metadata are documentation of the attributes of data directly attached to the data, and therefore can be archived along with the data.

Role of Data

The role and importance of data in C2 assessment is underestimated by many people, often including the decisionmakers and the assessment team itself. Figure 9.1, Data Taxonomy, lays out a number of the types of data including broad categories of sources that will be of interest to the analyst. The ability to determine the needed data and the ability to assemble or collect this data determine the solution strategy. The capability to obtain or collect the appropriate data:

- Will often reflect the difference between the desired or "ideal" measures of merit (MoM) and the set of MoM actually available and used in the assessment;

- Frequently either constrains or determines the scenario or set of scenarios that are used;
- Is a key or major factor in determining the set of tools appropriate for the assessment; and
- Often acts as a schedule and cost driver for the analysis.

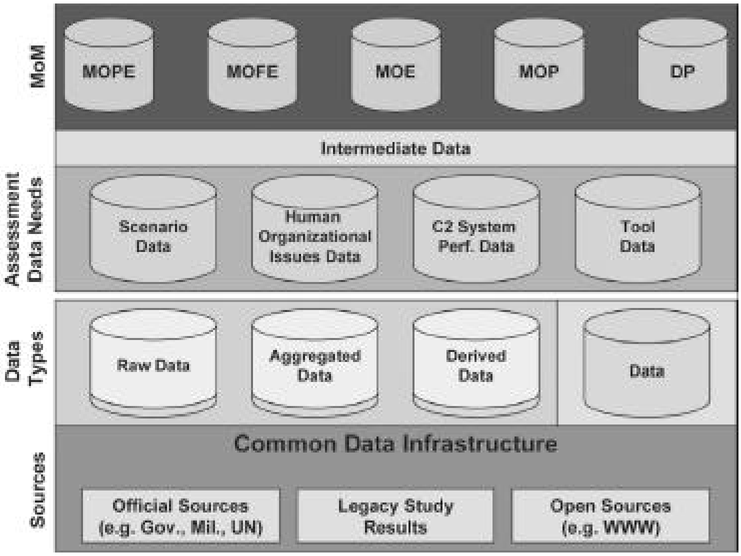


Figure 9.1. Data Taxonomy

Reuse of Data

Because of the centrality of data to the assessment, there is increasing interest in data reuse. While the amount of data potentially available for a given study is growing exponentially, the real opportunities for the reuse of data have proven to be limited because:

- The rapid change of technical data derailing performance of systems or sub-systems must be identified by version and data;
- Assessment teams do not always know that data exist and have no easy way to find out about such “legacy” data;
- The data that are available are seldom in an easily accessible form;
- The conditions under which the data were collected are not documented;
- The definitions, languages, and measurement instruments used in different analyses vary widely; and
- Restrictions arising from security considerations.

Despite these barriers, an effort should be made to find and reuse data. Sources that should be considered include “official sources” such as the customer, open sources such as those available on the Internet, and prior studies on similar topics. Because the data needed will seldom be available in a form and format ideal for the assessment, data engineering is often needed to gather, organise, and transform the available data.

Data generated by a given assessment phase may, in itself, be valuable as an input later in the research or to other project teams. To enable appropriate reusability of data, every modification, constraint, assumption, etc. has to be documented adequately. To facilitate the reuse of data, it is best practice to use metadata for this purpose.

In order to facilitate the reuse of data across community boundaries, alignment of the processes and methods for data and metadata modelling on the mid term—resulting in shareable data and metadata models and a common ontology on the long term—is necessary.

Furthermore, the issue of verification, validation, and certification (VV&C) for data becomes an issue of increasing significance. It is good practise to use certified data whenever possible.

Definition of Data Domains

Data can be directly connected to the other sections of the Code of Best Practice (COBP) by respective data domains. These data domains categorise what the information is about—and what data are available—as well as the assessment needs of the study—and what data are required. Some of these categories are:

- Scenario data: the set of data describing the scenarios and vignettes;
- Human organisational issues data: the set of data describing the scenarios and vignettes;
- System performance data: the set of data describing system performance in different scenarios; and
- Tool data: the set of additional data used for the tools that are not covered by any other category. Hard-wired assumptions belong here as well as study-specific configuration parameters used for technical calibration of tools. It is good practice

to be aware of the hidden data as well as the input parameters for each tool to be used within the study, especially when it is planned to build federations of tools.

Data Sources

Data can be obtained from various sources. The most common sources include:

- Official sources: sources such as military databases, governmental data, data owned by the United Nations, etc. The customer, or other stakeholders, controls the access to this data or is at least aware of the existence and structure of the data. It can be assumed that the customer will support the analyst in getting access to the data or a sanitised version, in case the original data are not releasable to the study.
- Open sources: data sources that are neither influenced nor controlled by the customer. The Internet, commercial organisations, as well as open data sources of non-participating organisations are examples.
- Legacy study results: data sources derived from other studies conducted by the operations analysis and operations research (OA/OR) community, including political, psychological, and sociological studies and Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) tests and evaluations. They may be the delivered as

the result of a former study as well as having been an intermediate result.

If needed data are not available from empirical sources, subject matter experts should be used as sources to estimate needed values.

Data Classes

Data classes describe the technical aspects of datum format, datum types, and stage of processing. Data classes identified in the context of this section are the following:

- Raw data are unprocessed. Raw data may come from observations of reality or artificial reality, the product of an instrumented reality, experimental situations, or selected artificial realities.
- Processed data and information are the result of transforming one or more raw data elements into another variable. For example, one or more radar returns are transformed into a track (friendly or not).
- Aggregate data and information are properties of a collection of elements. For example, the movement of individuals on a battlefield versus the movement of a squad or a platoon.
- Statistical values[1] are assessed on a sample of a population and characterised by this population. These include mean, modes, medians, standard deviations, and kurtosis. Statistics are often used as parameters in assessments.

- Derived data and information are outputs from a formula or simulation model that implicitly incorporates a set of assumptions. For example, loss-exchange ratios given sensor and weapons assumptions.

- Intermediate data and information are the products of one phase or component of the assessment that provides input to another phase or component.

Some C2 assessments use assumptions or preset parameters in place of data or statistics.

Use of Metadata

Data that are collected without adequate documentation are frequently viewed as suspect. To avoid having good data discarded due to a lack of documentation, acceptable community standards for documentation should be employed. The data must be clearly described in a manner that is understandable to a subject matter expert, not directly involved with conducting the study. The data description must be robust enough to inspire user confidence in the data. It is good practice to record these considerations in the metadata associated with the data to facilitate the data use and reuse.

Data may be in any of the relevant levels of measurement—ratio, interval, ordinal, or nominal. In C2 assessments, some significant factors may be nominal. It is good practise to record all of the assumptions, constraints, and limitations in the metadata.

In general, every time data are modified or processed to create new data, appropriate metadata documentation should be provided to ensure traceability of results, validation, verification, and certification of respective data, and reuse of data in later phases or within other studies. This also allows dealing with the challenge of multiple instances of data in different studies.

Data and Problem Formulation

The initial data available will often be vague, uncertain, incomplete, and contradictory. Analysts usually prefer data to be sharp, certain, complete, and consistent. It is necessary to be explicit about the assumptions inherent in this transformation.

If the assessment team finds it necessary to transform “soft” data to “hard” data in order to use tools that require “hard” data, it is best practice to record the source, perceptions etc. in the metadata associated with the data.

Obtaining Data

It may be safely assumed that not all of the required data will be available pre-packaged for the study question. Some relevant data will likely be submerged among a pool of irrelevant information.

Not all data will be under military/government control. Data belong to the stakeholders who are not necessarily connected to (or even friendly toward) the customer of the study. A lot of information is available from open sources. The challenge is to find, organise, verify, process, and convert it into the data needed.

The team should be aggressive and persistent in the pursuit of required data.

The data needed will seldom be available in its raw form. Often, data have been transformed and aggregated. When tools have to be applied to derive data, the derived data should be tagged with explanatory metadata to record that information in a form that will facilitate its reuse.

If the data are not available and can neither be aggregated nor derived from the available sources, it is good practice to use the knowledge of subject matter experts to generate the necessary data. Increasingly, when C2 assessment teams are tasked with exploring new concepts of operation, empirical data can not be expected to exist. It is further best practice to document this in respective metadata and replace such assumption based data as early as possible with empirical data, e.g., as soon as another study delivers the needed inputs. It is recommended to check the respective study results if subjectively generated data are replaced, particularly when the study result has been shown to be sensitive to this data element.

The team needs to know:

- What data are needed/structure of data;
    - Preferred data (independent variables within the MoM);
    - Necessary data (to be able to drive the tools);
    - Available data (derivation, extraction, collection, etc.);
- Who owns this data;

- Security issues, possibility of declassifying or otherwise obtaining release may be another issue;
- Costs to;
    - Buy data;
    - Collect data (people, time, resources); and
    - Generate data.

It is essential to make the value of data clear to all levels of decisionmakers and operational planers to ensure that data collection issues are included in all phases of the study. The data collection and engineering plan, as introduced in section 4-E-4, as part of the solution strategies, has to take this into account.

The process of data acquisition is important, but data acquisition should not be emphasised over data interpretation.

There is an increasing urgent need for data describing operations over the complete mission spectrum. It is good practise to collect and exploit operational data whenever possible. It is therefore recommended to synchronize respective data collection and engineering plans, ensuring from the start that the desired data will be collected and archived appropriately.

The Use of Data within the Study

The archiving of data in retrievable form is essential. This is necessary both to support the ongoing study and also to be of value for future study efforts. The team should establish and adopt process models that ensure the build-up of archives within a respective infrastructure. Metadata have a critical role to play in data archiving and retrieval.

The discussion of data, and the development of a community database, must be driven by agreed upon definitions of data that are sufficient to support the community. This should be a high priority item.

Data can be described as the “glue” that holds together the different phases of a study. As the results from one phase are transported to the next it is unlikely that both will use identical processes and procedures, therefore harmonised data formats will allow for smooth transition and continuity of effort.

The analyst will be faced with data in various forms and formats. In order to consider all available data, find it if necessary, and format it in the required manner (e.g., as an input parameter for the MoM or a model) data must be stored appropriately. One standard for storing data is the Information Resource Dictionary Systems (IRDS) [ISO 1990].

IRDS is a layered database that not only comprises the data, but also the metadata describing the meaning of the data, the format, the constraints, the intended use, the source, degree of certainty, vagueness and reliability, etc. It comprises data as well as metadata.

A common understanding of the problem between the customer and the study group as well as among the interdisciplinary study team is essential for the success of the study. Therefore, a study glossary—based on a general and evolving OR glossary (e.g., the NATO JOINT Pub 1-02 [US DoD 1999])—is needed. The data definitions stored as metadata have to be aligned with the definitions found in the study glossary. This provides a basis for standardised documentation of study results in a highly reusable form that can be manipulated easily and reliably, perhaps by automated systems.

Using the right toolkit for the management of data within the IRDS, such as the Shared Data Environment (SHADE), can create the initial state of every future data driven application. (DISA, 1996; Krusche and Tolk, 2000). The same techniques and tools can and should be used for information systems delivering the needed functionality to the warfighter and decisionmaker. (Tolk, 2000).

Conclusions and Recommendations

Data transcend all phases of an assessment and may be seen as the "glue" that holds the phases of an assessment together. Given its importance, resources must be committed to ensure effective data acquisition, management, and availability for reuse.

There is an urgent need to agree on standards for data, metadata, and data management, including the conditions under which the data are collected, data element definitions, metrics, etc. It is good practise to use established standards, where appropriate, such as the Source for Environmental Representation and Interchange (SEDRIS™), or to use de facto standards like Digital Terrain Elevation Data (DTED).

As the data being used today by the analysts will be the data needed tomorrow by systems engineers, decisionmakers, and commanders for their operations, alignment of the standardisation processes and the respective toolsets as early as possible with the command and control systems community is good practice. A significant first step in such an alignment would be using the same IRDS [NATO 1999]. A common C4I and Modelling and Simulation (M&S) community is needed, to make visions like integrated alternative course of action analyses become a reality.

Chapter 9 Acronyms

C2 – Command and Control

COBP – Code of Best Practice

C4ISR – Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance

IRDS – Information Resource Dictionary Systems

MoM – Measures of Merit

M&S – Modelling and Simulation

OA/OR – Operations Analysis and Operations Research

SHADE – Shared Data Environment

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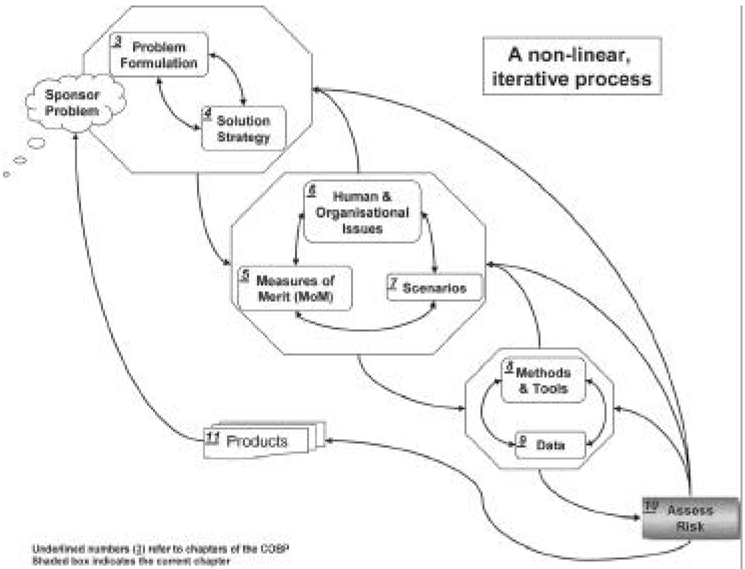
[1]Statistics is a branch of mathematics dealing with the collection, analysis, interpretation, and presentation of masses of numerical data; alternatively, statistics is a collection of quantitative data. (Webster Online Dictionary).

CHAPTER 10

Risk and Uncertainty



We may at once admit that any inference from the particular to the general must be attended with some degree of uncertainty, but this is not the same as to admit that such inference cannot be absolutely rigorous, for the nature and degree of the uncertainty may itself be capable of rigorous expression.

—R.A. Fisher, *The Design of Experiments*

There are risks associated with the decisionmaker's situation that are an inherent part of the analysis. There are also risks related to the conduct of the analysis itself. This chapter deals with both of these sets of risks, focusing upon reducing uncertainty and other contributors to risk as well as the mitigation of their effects. Failure to deal effectively with risks will jeopardise the accomplishment of the goals of the study, namely to provide high quality decision support. It should be noted that, by the end of the assessment, the team will generally be aware that the initial study plan will have been changed, whereas flaws in the conceptual model or in the assessment design may remain hidden for some time from both the analyst and the decisionmaker.

While the adoption of the guidance contained in this Code of Best Practice (COBP) will help minimise the risks, it will not eliminate them. This chapter discusses a number of issues related to the risks and uncertainties that the assessment team needs to explicitly address.

Risk

Risk is commonly defined as the possibility of suffering harm or loss; in other words, an exposure to harm or loss.[1] This includes an opportunity loss. The difference between risk and loss is that risk inherently involves before the fact probability, while loss is an after the fact certainty. Insurance is about estimating and covering an exposure of value to uncertainty. Risk often has a negative connotation, yet "taking risks" can also be a positive act when a proper balance or trade-off is made between good and bad outcomes and the respective probabilities associated with the outcomes.

Perceptions of risk can substantially differ from more objective assessments of probability and impact. This is particularly important in command and control (C2) problems, which have a high sociological content.

Uncertainty

Uncertainty can be generally defined as an inability to determine a variable value or system state (or nature) or to predict its future evolution. Uncertainty is inherent in risk. Even if a person is certain about the possible outcomes and the probabilities associated with these outcomes, there is uncertainty about which outcome will in fact occur. When this situation applies we can say that we have a known risk. For example, the possible outcomes and the probabilities associated with the toss of a coin (and many other popular forms of gambling) are known. What is uncertain is the outcome. Hence there is a risk, in this case a known risk, associated with obtaining a particular outcome.

There are other types of uncertainty, including uncertainty about the possible outcomes (or their values) and uncertainty about the probabilities associated with these outcomes. Uncertainties arise from other uncertainties, namely uncertainties about the potential actions of others or what is referred to as "states of nature" and their associated probabilities. In C2-related assessments, in particular, perceptions of uncertainty may substantially differ from a more objective assessment of lack of knowledge. There are also a number of uncertainties that are associated with the assessment itself. These are discussed later in this chapter.

Dealing with Risk

There are three basic ways to deal with risk. The first is to reduce the uncertainty that underlies the risk. The second is to mitigate risk by developing and selecting risk-averse strategies. The third is to effectively communicate the nature of the risk involved.

Reducing Uncertainties

In effect, all methods for reducing the uncertainties that underlie risk involve the collection or analysis of information. This is, of course, a major focus of an assessment. Clearly the assessment team needs to identify the most important uncertainties—a combination of the degree of uncertainty and the consequences of that uncertainty. However, there will always be some significant residual uncertainties. The aim of the assessment team, at this point, is to reduce the risk associated with the study by learning more about the robustness (or lack thereof) of the study findings and conclusion. Sensitivity analysis is one method to accomplish this purpose.

Sensitivity Analysis

The goals of sensitivity analysis are fourfold:

- To establish the regions for which established results are valid;

- To isolate those factors that contribute most to the uncertainties that exist and identify the risks associated with these uncertainties as they relate to study findings and conclusions;
- To make study results more robust for decision support by allowing the decisionmaker to see the immediate consequences as external factors are changing; and
- To give the decisionmaker a richer understanding of the decision problem, highlighting the consequences of limited changes relative to a solution proposed by the study.

The team should take a three-step approach:

- Identify the variables that are associated with the greatest combination of risk and uncertainty;
- Perform sensitivity analyses that vary across the more likely region of key parameters (often the neighbourhood of the initial estimate) to see how the result is influenced. A sensitivity analysis investigates the main region of the output space; and
- Investigate the extremes of the same output space, focusing most strongly on the negative regions.

The assessment team also partially takes an inverted approach, looking for possible failures, and then seeking possible sources of each kind of failure.

Together, these three steps should provide the team with a better understanding of residual uncertainties and associated risks. The need for and results of sensitivity analyses must be stressed in discussions with the decisionmakers. This will help avoid the under-resourcing of this critical activity.

Uncertainty and Risk in C2 Assessments

Uncertainty and the risks associated with it can not be totally eliminated in any real world C2 assessment problem. Moreover, in most real-life problems, one cannot even identify all of the unknowns. This has given rise to the term the “unknown unknowns.” Strategies to minimise risk have evolved to handle these facts of life. Therefore, even the best possible assessment approach will result in residual uncertainty and risks.

In general, assessments should be judged by their ability to reduce uncertainty so that the decisionmaker is in a better position (less risk) after the assessment than before the assessment. Looking at the absolute uncertainty that remains is not as useful a measure since it may say more about the nature of the problem than the success of the assessment.

Dealing with Uncertainty

It is important to treat uncertainty consistently and explicitly. This allows information from two given sources or results to be fused, (e.g., by taking the most precise assessment of each factor from the two results). Thus the resulting knowledge will be better than either of the two separate results. On the other hand, if uncertainty is not treated explicitly or consistently, the best one can do is to pick the single result that seems best. This makes it more difficult for a study to add value to a decisionmaker.

C2 issues are complex, and it is an understatement to say they are incompletely understood. C2 requirements and solutions tend to depend heavily on the nature of the operating environment. Thus, a C2-related study will rely on factors that are imprecisely determined and change frequently over time. Almost regardless of the assessment effort, parts of the problem-space will have been investigated less thoroughly than would be ideal. Sensitivity analyses are required to give high quality study results.

C2 assessment problems (particularly in operations other than war (OOTW) contexts) generally have many interacting factors. It is unwise to rely upon single factor sensitivity analysis (i.e., testing sensitivity to one factor at a time). Multi-factorial experimental design methods are good practice in such circumstances. (Keppel, 1973).[2]

OOTW studies typically have less well-formed quantitative factors and more qualitative factors. The "softer" nature of these factors makes assessment more difficult. The types of factor seen in OOTW problems include:

- Social and political activity impacting the tactical level;
- A strong influence of negotiation and persuasion as opposed to coercion;
- Non-optimal performance of military capabilities from a technical perspective due to their poor fit to the problem;
- Severe rules of engagement (ROE) constraints; and

- Unclear or evolving goals and objectives.

The team must be aware of the assumptions and limitations included in models, scenarios, and data structures, which should be captured in the metadata. In particular, it should be noted that humans involved in C2 experiments (as analysts or subjects) always bring assumptions with them. These need to be identified and collected to form an audit trail. This is one place where the project leader's log of assumptions and decisions made during the assessment pays off. Uncertainty over the validity of these assumptions and limitations provide a source of uncertainty in study results to which study conclusions must be made robust.

In C2 assessments, in particular, all aspects of a study and study-problem may be connected to uncertainty. Thus, different sorts of uncertainty should be addressed explicitly at appropriate stages in the study. Examples of these are:

- Parameter value uncertainty—many of the parameters and factors in C2 assessment are difficult to evaluate confidently;
- Model-based uncertainty—i.e., over whether underlying models are valid and representative;
- Uncertainty of focus—i.e., over whether the assessment covers all of the important factors and/or issues (this includes uncertainty of scenarios); and
- Complexity of uncertain factors (i.e., their dimensionality)—when a sufficiently complex factor (e.g., scenarios or future technology) is

uncertain, the team can not expect to overview the set of all possible true states.

Uncertainty in complex factors, such as scenarios, should be addressed thoroughly. Even though it is philosophically impossible to know everything about a problem, an adequately complete knowledge can be better assured by explicit use of checklists that highlight the breadth of factors typically involved in C2 assessments, such as:

- Technology—disruptive uncertainty and disruptive innovation;
- Organisational use of technology;
- Scenarios, tasks, and nature of operations;
- Data;
- Context or environment of the assessment; and
- Co-evolution of factors (e.g., summarised in doctrine, organisation, training, material, leadership, personnel, and facilities [DOTMLPF]).

Nonetheless, the team should not rely completely on checklists, but rather complement them with critical thinking in the specific study context.

Within electronic systems, organisations, and battle concepts, there is a lot of opportunity for disruptive technology, producing substantial uncertainty. In human-in-the-loop experiments there is a greater danger of bias in subjective judgements.[3]

In considering sensitivity analysis, it is important not to associate it only with statistical variance in parameter values. Qualitative consideration, such as variation of model, perspective, or assumptions (i.e., categorical variations) should also be used to test for and assess sensitivity. Variations in ranking (ordinal variation) can also be a powerful tool for sensitivity analysis. Other analytic tools and constructs relevant to sensitivity analysis are:

- Non-parametric statistics (Siegal and Castellan, 1988);
- Belief-functions (as an alternative to probability);
- Judgmental uncertainties (Wilson and Corlett, 1990);
- Fuzzy numbers, theories of semiorders, scoring criteria (Siegal and Castellan, 1998);
- Multi-dimensional scaling; and
- Mathematics applied to non-ordinal scales.

Semiorders constitute the intermediate level between ordinal information and value. They apply to many fields but in this context especially to scored data or preference data—in that account is taken of the intervals of imprecision around the measuring systems used. Analysts should be aware of the thresholds associated with the collected data above which differences can be legitimately distinguished to produce values. This idea is very useful when the measurements cannot be repeated (as in statistical theory) (Prilot and Vincke, 1997).

Keeping C2 assessment rigorous and robust in the face of the many uncertainties and complexities of the subject matter, as well as the need to use a rich combination of methods, can be difficult. Again, it is good practice to use checklists and structured appraisal, in this case to maintain an objective view of study rigour. The choice of checklist or appraisal structure can depend upon personal preferences, but Annex F lists a number of structures, which have proved useful in the experience of the nations contributing to this COBP. These include:

- Repeatability, independence, grounding in reality, objectivity of process, uncertainty and robustness (RIGOUR); and
- Strengths, weaknesses, opportunities, and threats (SWOT).

Where an assessment uses experimentation or observation of exercises it is important to identify independent and dependent variables and, for the former, which are controllable, which are measurable, etc. Figure 10.1, for example, illustrates the variety of variables that need to be considered when studying decisionmaking.

A thorough understanding of the variables of a study is essential for effective treatment for uncertainty.

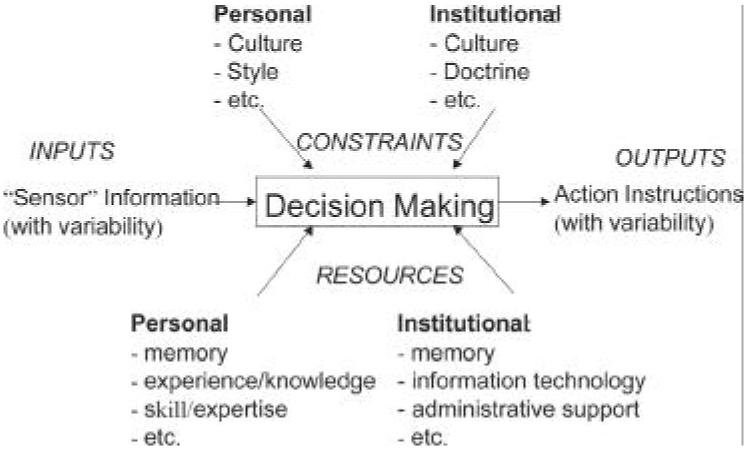


Figure. 10.1. Illustration of the Variety of Variables Relevant to Decisionmaking

Risk-Based Analysis

In cost-benefit or cost-effectiveness analyses there has historically been a tendency to focus on the single most likely value (its expected value) for each input factor (including scenario and course of action) and to "solve" the problem based upon these point estimates. This can lead to fragile solutions, which do not provide decisionmakers with help in dealing with the uncertainties and associated risks inherent in the real problem. A risk-based approach can overcome some major pitfalls by adding a focus on the multiplicity of possible outcomes and opening up the possibility of richer solutions involving portfolios of action that produce robustness rather than narrow optimality. Portfolio-based solutions can be associated with cost-benefit approaches, but this has not been common in practice.

The subject of C2 assessments is typically both highly uncertain and opaque in nature. The team should, therefore, expect a complex and partly hidden set of risks to C2 studies and C2-related decisions. It is recommended that serious efforts be made to illuminate the risks, and it is good practice to include an explicit risk-based analysis in the study and in study planning.

Different people have different worldviews and different approaches to risk taking. Analysts should seek to find out about how risks are traded for expected gain by the study sponsor so that their worldview can be appropriately represented in the assessment.

Risk-based analysis needs metrics for risks and failure as well as success and benefits, which means that one needs a way of expressing various levels of all of these dimensions.

In C2 assessments, analysts need to be particularly alert to the possibility of chaotic behaviours arising from dynamic interactions. Human and organisational factors are particularly prone to this type of instability. A sound and explicit treatment of boundaries and system definitions during problem formulation is essential to managing this aspect of the assessment. Holistic systems thinking and complexity-based analysis may be needed for this purpose.

When dealing with problems involving human decisionmaking the analyst must be aware of the diversity of courses of action that are possible as the situation evolves. The analyst must ensure that these courses of action are represented in a way that allows for the possibility of a discontinuous set of possible future states. If wide divergence in course of action selection is possible over the timescales under consideration, then the treatment of scenarios may be particularly problematic and may require explicit consideration under the risk and sensitivity heading.

Managing Study Risk

C2 assessments are inherently complex. They often contain poorly understood study problems. These factors enhance the level of risk in the design and conduct of the assessment.

It is good practice to try to make a complete list of risks and then treat them in appropriate detail. A top-down approach may be useful in assuring a certain degree of completeness. Independently of the depth of each concrete study, it is good practice to use a risk perspective to explicitly assess the robustness of a conclusion or recommendation. If possible, one should try to keep track of which mechanisms underlie each risk, the probability that it will occur and how it can be mitigated, then consider cost of mitigation and cost of risk impact, before taking a cost-benefit approach in managing the study risk level.

C2 problems are often weakly bounded. There is a particular risk associated with problem formulation and the identification of factors. Annex F lists a number of checklists, which have proved useful in ensuring an adequately complete treatment of the multiple risk areas.

The Generic Risk Register

The generic risk register for C2 assessment (GRR) is a good starting point for a risk-based analysis of a study project (not the decision problem supported by the study). The lists of risks, consequences of impact, and mitigation recommendations are directly derived from the COBP. They are, therefore, generic in their form and should only be taken as a starting point for a project-specific risk analysis. The GRR has functionality, which allows it to be used as a basic tool, or the list of risks can be copied into a more elaborate tool used for risk handling in the project.

An illustrative example is the case study undertaken by the SAS-026 study group, when a brief journey of only an hour through the generic risk register turned out very useful. Although the study team was well aware of the advice and possible pitfalls in advance, explicitly addressing them with a risk perspective led to the recognition of two significant flaws:

- The low number of planned iteration had the potential to lead to a risk of an inefficient and unfocused study with possibly misleading results; and
- The relatively narrow selection of methodological approaches entailed a risk of misleading conclusions. There could be important consequences of varying the C2 system that were not reflected in the study, and the possibly biased representation would represent a hidden flaw in conclusions.

The example illustrated both the usefulness of making the risk assessment explicit, since these problems were actually known to all participants prior to the risk management session, and also illustrated that even surface scratching (as was the case here) may lead to significant results. *It is, therefore, advisable not to skip risk analysis even when time and resources are limited*.

Communication of Risk and Uncertainty

The high level of uncertainty (and hence risk) in C2 problems and their assessment mean that the communication of risk and uncertainty to study customers, sponsors, and stakeholders is of particular importance. The value of a quality assessment is that it provides decisionmakers with the evidence they need to make better decisions. The nature and quality of evidence required depend upon the decisionmaker's approach to and tolerance for risk-taking and his/her level of prior knowledge of the problem area being assessed.

Communication is about giving the receiver of a message a right impression, not about formulating a statement that is formally correct on its own. This might seem obvious, but in communicating uncertainties and risk, it should be given particular attention, since the complexities of the subject, human limitations in reflecting on uncertainty, and the lack of a common set of concepts (and also hidden agendas) often will make communication far less than perfect.

As discussed earlier, some uncertainty can be reduced by analysis. However, some uncertainty is inherent in the problem and needs to be exposed to the decisionmaker. A failure to do this can lead to false confidence in study conclusions. C2 assessments, in particular, will contain many areas of unresolvable doubt and uncertainty. These should be openly and honestly communicated to decisionmakers to avoid misinterpretation of study conclusions. *Support to decisionmaking under uncertainty is a vital complementary activity to C2 assessment*.

Different ways of framing results and uncertainties may strongly influence the way results are perceived. This should be considered thoroughly to assure compliance with ethical standards. One should be aware that stakeholders (including customers) might have a tendency to gloss over or alternately over-focus on uncertainties. An analyst should take care in communicating an objective impression of risks and uncertainty.

Limitations and shortcomings in a study are a crucial part of the study result and should be communicated as effectively as possible. This enables alignment of study results and background knowledge on the problem.

Human ability to understand and reason on uncertainty is limited. (Kahnmann et al., 1982). These limitations should be given particular attention when communicating risk and uncertainty to stakeholders and decisionmakers.

People with different backgrounds will have different concepts of uncertainty (e.g., people without some mathematical background won't necessarily intuitively understand Bayesian concepts). Thorough dialogue may be needed to find a common language. Visualisation techniques will be helpful in this regard since they are usually more powerful than verbal reference to abstract concepts.

One should be careful not to overwhelm an audience with details on uncertainties and possible shortcomings. However, *a continuing dialogue about uncertainty will facilitate a common understanding*. Also, the analysis team should be aware of the possibility that residual uncertainties may make it impossible to draw robust conclusions.

Conclusions

The explicit treatment of risk and uncertainty is best practice in all studies and is of particular importance in C2 assessment. A variety of dimensions and aspects of C2 assessments carry risk and uncertainty, particularly because they are liable to include complex, interacting factors. Even when study resources are limited, it is best practice to include both an assessment of most likely outcome (result), to do sensitivity analyses looking for other likely outcomes, *and* to take a risk-based approach looking for the more extreme possible outcomes (in particular failures).

The use of checklists is recommended to ensure a rigorous treatment of risk and uncertainty. The best choice of checklist depends upon personal preference, but a number of examples are presented that have been found useful by the nations contributing to this COBP. Additionally, the GRR has proved useful as an aid to C2 study risk management.

Chapter 10 Acronyms

C2 – Command and Control

COBP – Code of Best Practice

DOTMLP – Doctrine, Organisation, Training, Material, Logistics, Personnel

DOTMLPF – Doctrine, Organisation, Training, Material, Leadership, Personnel, Facilities

GRR – General Risk Register

METT-TC – Mission, Enemy, Troops, Terrain, Troops, Time, and Civil considerations

OOTW – Operations Other Than War

PESTLE – Political, Economic, Social, Technological, Legal, and Environmental

RIGOUR – Repeatability, Independence, Grounding in reality, Objectivity of process, Uncertainty, and Robustness

ROE – Rules of Engagement

SWOT – Strengths, Weaknesses, Opportunities, Threats

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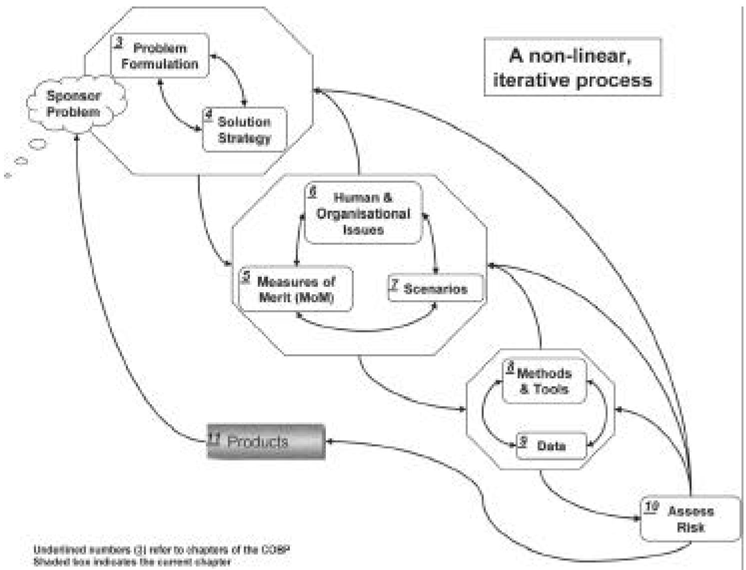
[1]This interpretation of risk is used throughout this section. However, other common definitions have been included at Annex E as an aid to common understanding.

[2]Tom Lucas' work in Project Albert.

[3]These types of experiment are typically unrepeatable due to resource constraints.

CHAPTER 11

Products



We are what we repeatedly do. Excellence, then, is not an act, but a habit.

—Aristotle

The purpose of study products is threefold: to communicate results to sponsors and stakeholders; to provide a lasting record of what went into the planning; and to establish credibility within the technical community. Verbal communication and progress reports may be necessary, especially for a short study, however a thorough written record is essential to the credibility and longevity of study results.

Study products that are delivered to the customer generally include a study plan, periodic status/progress reports, and a final report. Several other products may be produced and delivered to the customer. Some study products are created and maintained primarily for internal study support. These products are not unique to C2 OOTW studies or to general C2 studies.

Products that are typically produced from a study include:

Study Plan

The study plan described here is a subset of the Study Management Plan of section 4-E. It generally includes the initial problem formulation and solution strategy, emphasizing a general understanding of the problem, deliverables, budget, time line, and solution approach. The study plan includes at a minimum:

- Statement of the problem (problem formulation)—“the what”;
- Solution strategy “the how and the when”;
    - Tasks and their relationships; and
    - Milestones.

Periodic Status/Progress Reports

Periodic status reports describe the activities of the most recent period and the expected activities of the next period, and link the activities to the tasking statement. Status reports also contain cost information and track adherence to the planned schedule. One of the most important sections of the status report is the “Problems

Encountered" section. This section should include technical problems, budgetary problems, and most importantly problems relating to sponsor/assessment team relations. These reports may be delivered:

- To the sponsor and other stakeholders; and
- To the peer review team.

Final Report

The final report contains sections that address the following:

- Objectives (customer question and the problem formulation);
- Scope and assumptions;
- Approach (solution strategy);
- Findings/conclusions (with caveats);
- Recommendations (optional);
- Future challenges (optional);
- Appendices;
  - Data collection instruments or discussion of instrumentation (optional);
  - Data dictionary (optional);
  - Data (optional);
  - Glossary of terms/acronyms; and
  - References.

The findings/conclusions and recommendations (if present) should address each of the objectives.

The final report should be produced as an archivable document that can be readily accessed by the community. This means that the document is produced in electronic form using commercial standards. Ideally these documents should be made available through web sites. However, it is recognised that security considerations and language will limit the availability of many documents. Briefings are a useful form of communication. It is desirable that a briefing accompany the more formal final report. However, when only a briefing is produced, it must be annotated.

Command and control (C2) problems tend to be multi-dimensional and highly complex. Therefore, they pose unique challenges to the assessment team in communicating the result effectively to the decisionmaker. There are several steps that can be taken to facilitate this communication. First, if the product is an architecture, it is recommended that the templates developed by community to depict alternative architectural perspectives (e.g., operational, system, and technical architectures) be employed. Second, it has proven useful to employ "stop light" charts (red, yellow, and green) to characterise measures of performance/effectiveness. However, such techniques are useful only in conveying qualitative insights. A tendency to rely heavily upon this presentation technique may result in assessments that do not drive to quantitative results. Third, there is a need to develop and employ visualisation techniques to capture the full richness of the insights, particularly risk and uncertainty (e.g., depicts the distribution rather than just the statistical) that are derived in assessments. Preliminary research is underway in this area. It needs to be extended and translated into application.

Because C2 data are rare, every effort should be made to retain the data and make it available to other recorders. Sometimes others will require “sanitising” the data to prevent anyone knowing which units or exercises produced it. When archiving data the metadata labels that identify the conditions under which it was collected should also be preserved.

A peer review process is an essential part of producing a final report. It should begin with the preparation of the study plan and continue throughout the life of the assessment. Draft products must be provided to reviewers in ample time for them to review and comment on the product and for the team to reflect their comments. *A failure to institute an adequate review process can compromise the quality, credibility, and utility of the assessment*.

Other Delivered Products

Several products may be created and delivered, depending on the needs of the project:

- Description of the assessment participants (including assessment team) and their relationships (defined in 2-B);
- Description of the budget and time constraints to provide context information for future studies;
- Human and Organizational Factors Checklist;
- Scenario details

- Video and audio presentations; and
- Created models, spreadsheets, decision support tools, etc.
- Simple models and tools (EG for the sponsor and other parties to interactively explore interrelationships between the variables of the study);
- Experimentation Campaign Plan (if the C2 Assessment makes use of a series of linked events such as seminars, wargames, command post exercises (CPX), field training exercises (FTX) etc).

Other Products

In addition to study products that are delivered to the sponsor there are a number of products that best practice demands are produced and maintained during the course of a study. These include:

- A project journal;
- Study Management Plan (defined in 4-E)
- Data collection plan;
- Data analysis plan; and
- Study Glossary

Conclusion

A study is generally appraised based on the quality of its study products. This Code of Best Practice aims to highlight important areas that will improve both the assessment process, and the quality, longevity, and utility of the study products. The goal is to make the state of practice one and the same with the state of the art.

> *Of all the communities available to us there is not one I would want to devote myself to, except for the society of the true searches, which has very few living members at any time…*
>
> —Albert Einstein

ANNEX A

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The following additional documents are under development:

NATO C3 System Baseline Architecture

NATO C3 System Overarching Architecture

ANNEX B

Acronyms

A

ACCES	Army Command and Control Evaluation System
ACE Resources	Allied Command Europe Resources (part of SHAPE)
AF(N)	Regional Command
AHWG	AC/243 Panel 7 Ad Hoc Working Group
AI	Artificial Intelligence
AMF(L)	ACE Mobile Force (Land)
ANT	Actor Network Theory
ARRC	ACE Rapid Reaction Corps
ATS	Norman's Activation Trigger Scheme

B

C

C2	Command and Control

C3	Command, Control, and Communications or Consultation
C3I	Command, Control, Communications or Consultation, and Intelligence
C4	Command, Control, Communications or Consultation, and Computers
C4I	Command, Control, Communications or Consultation, Computers, and Intelligence
C4ISR	Command, Control, Communications or Consultation, Computers, Intelligence, and Surveillance and Reconnaissance
CIMIC	Civil-Military Co-operation
CIS	Command Information Systems
CISS	Center for Information Systems Security
COBP	Code of Best Practice
CPX	Command Post Exercise
CTA	Constructive Technology Assessment

D

DCEP	Data Collection/Engineering Plan
DISA	Defence Information Systems Agency
DOTMLP	Doctrine, Organisation, Training, Material, Leadership, Personnel
DOTMLPF	Doctrine, Organisation, Training, Material, Leadership, Personnel, Facilities/Forces

DP Dimensional Parameters

DSTL Defence Science and Technology Laboratories (UK)

E

EEA Essential Elements of Analysis

F

FS Feasibility Study

FTX Field Post Exercise

G

GRR Generic Risk Register

H

HB(A) UK Historical Branch (Army)

HEAT Headquarters Effectiveness Assessment System

HQ Headquarters

I

IO International Organisation

IRDS Information Resource Dictionary Systems

IRTF(L)	Immediate Reaction Task Force (Land)

J

JCSC	Joint Sub-Regional Command South Centre
JCSE	Joint Sub-Regional Command South East
JFCOM	Joint Forces Command

K, L

M

MAPEX	Map Exercise
MAUT	Multi-Attribute Utility Theory
MCES	Modular Command and Control Evaluation Structure
M-E-M	Model-Exercise-Model
METT-TC	Mission, Enemy, Troops, Terrain, Troops, Time, and Civil considerations
MND(C)	Multinational Division (Centre)
MoCE	Measures of C2 Effectiveness
MoE	Measures of Effectiveness
MoFE	Measures of Force Effectiveness
MoM	Measures of Merit

MoP	Measures of Performance
MoPE	Measures of Policy Effectiveness
MORS	Military Operations Research Society
M&S	Modelling and Simulation
M-T-M	Model-Test-Model

N

NATO	North Atlantic Treaty Organization
NC3A	NATO C3 (Consultation, Command & Control) Agency
NGO	Non Governmental Organisations
NL MOD	Netherlands Ministry of Defense

O

OA	Operational Analysis
OOTW	Operations Other Than War
OR	Operations Research

P

PESTLE	Political, Economic, Social, Technological, Legal, and Environmental
PfP	Partnership for Peace
PRL	Policy Requirements Land

PVO	Private Volunteer Organisations

Q

R

RIGOUR	Repeatability, Independence, Grounding in reality, Objectivity of process, Uncertainty, and Robustness
ROE	Rules of Engagement

S

SACLANT OA	Supreme Allied Command Atlantic Operational Analysis Cell
SCOT	Social Construction of Technology
SFS	Strike Force South
SHADE	Shared Data Environment
SHAPE	Supreme HQ Allied Powers Europe
SMP	Study Management Plan
SOW	Statements of Work
STA	Surveillance Targeting and Acquisition
STAFFEX	Staff Exercise
STS	Science and Technology Studies
SWOT	Strengths, Weaknesses, Opportunities, Threats

T

TA	Technology Assessment
TRAC	TRADOC Analysis Center
TRADOC	US Army Training & Doctrine Command
TTP	Tactics, Techniques, and Procedures

U

V

VTC	Video Teleconference
VV&A	Verification, Validation, and Accreditation
VV&C	Verification, Validation, and Certification

W

WBS	Work Breakdown Structure

X, Y, Z

ANNEX C

The MORS Code of Ethics

The MORS Code of Ethics and Responsibilities for Practitioners of Military Operations Research

Military OR Professionals must aspire to be:

- Honest, open and trustworthy in all their relationships;
- Reliable and consistent in the conduct of assignments and responsibilities, always doing what is right rather then expedient;
- Objective, constructive and accurate in what they say and write;
- Accountable for what they do and choose not to do;
- Respectful of the work of others, giving due credit and refraining from criticism of them unless warranted; and
- Free from affiliation with others or with activities that would compromise them, their employers, or the Society.

ANNEX D

Human And Organisational Issues Checklist

This checklist presents a summary of a particular set of human and organisational issues that is specifically relevant to behaviour and performance of humans in command and control situations. Its purpose is to sensitise the analyst and help him to assess whether human or organisational issues are part of the problem domain and should be addressed in the solution space. Also, it should assist him in identifying human sciences disciplines for consultation.

It should be pointed out, however, that this checklist is preliminary and must not be considered to be comprehensive. The field of human sciences is too large and the set of human and organisational issues to ill defined to provide the analyst with an exhaustive checklist, at this time. Research in this area is ongoing and we expect that later editions of this document will provide the analyst revised and improved checklists.

1. **Human Issues**

- Physiological factors

This refers to bio-medical and environmental factors that influence behaviour and performance

- Stress
- Fatigue and lack of sleep
- Blood sugar
- Fitness conditions
- Weather conditions
- Geographical terrain conditions

- Ergonomic factors (e.g. performance degradation due to working in protective suits)

Ergonomics is a science discipline that studies human work and work environment relationships.

- Behavioural factors (related to functioning in a C2 group)
    - Social Competence & Experience

        Capability to interact with others

        - Communication skills
        - Language skills
        - Empathy (Social Awareness/ understanding)
        - Conflict handling style
        - Frustration handling style
    - Military Competence & Experience
        - Handling Danger

    - Defining mission objectives
- Task Competence & Experience
- Cognitive factors

These factors are related to how humans perceive their environment, how they give meaning to what they see.

    - Information processing style
    - Information processing capacity
    - Creating Situational Awareness
    - Individual decision making
        - Risk tolerance
        - Pre-disposition!
        - Receptivity to new information (open / closed)
        - Expertise
        - Prior training and knowledge (operational codes)
- Emotional factors
    - Morale
    - Attitude
    - Separation from Family
    - Fear
    - Stress

    - Resilience (ability to overcome negative feedback)

- Leadership factors

  There exists no clear-cut concept of leadership effectiveness, but we do know some of the factors that affect the effectiveness of a leader

  - Expectation and behaviour of superiors
  - Expectations and behaviour of subordinates
  - Expectations and behaviour of colleagues
  - Personality and experience
  - Organisational Culture and policy – with regard to leadership and command. Allocation or responsibility and authority.
  - Ability to Motivate and to Direct others
  - Moral and Judicial responsibilities
  - Coaching capabilities (towards subordinates)

2. <u>Organisational Issues</u>

- Structure
  - Number of echelons or layers
  - Span of control for nodes
  - Pattern of linkages between nodes (e.g. hierarchical, multi-connected)
  - Permanent versus transitory

    - Formal versus Informal
- Function
    - Distribution of responsibility
    - Distribution of authority
    - Distribution of Information
    - Functional Specificity
    - Ambiguity in command relationships
- Capacity
    - Differences in communication systems / Architectures
    - Differences in information processing systems / architectures
    - Differences in field training and operational experience
    - Differences in personnel
        - Experience
        - Training
        - Cognitive ability
- Roles
    - Allocation of Responsibility / Authority
    - Role Conflicts. The interference of multiple Roles in one individual
- Sociological factors
    - Understanding of environment

        - Political
        - Social
        - Cultural
- Interoperability Issues
    - National and cultural differences
    - Organizational approaches and values
    - Communication standards and technology
    - Differences in perceptions
- Organisational command style
    - Decentralised or Centralised
    - Collaborative versus Authoritative
    - Formal versus Informal
    - Command products: orders, objectives, missions
- Organisational Culture

  Shapes patterns of organisational behaviour and reflects thought and activity patterns by members of the organisation.

    - Belief systems
    - Organisational norms & how are they expressed
    - Organisational values & how are they expressed
        - Open to organisational learning

I.e. does the organisational culture embed characteristics that enable and facilitate organisational earning?

3. <u>Interaction between Human and Organisational Issues</u>

- Group decision making

  Groups can exert social pressure on members that affect the decision-making capability of individual members.

- Group Dynamics

  The behaviour of individuals in a group will be influenced by the fact that they are interacting in a group. This interactive process contains a number of dynamic dimensions and does effect the result of interaction. A command post is a group of people and its performance is affected by it group dynamics.

  - Social interaction & communication
  - Communication
  - Social Identity and social conflicts
  - Individual dominance/leadership
  - Cohesion
  - Teambuilding, teamwork

- Trust in group member's competence and loyalty.

- Cultural factors

Culture is more or less the whole of beliefs and assumptions, including norms and values, about things and behaviour in a group. As such it guides the behaviour of people, also in the military and in command posts.

- Note! Culture itself is immaterial, intangible. It can only be distilled form observed actions by members of an organisation or societal group
- Note! Culture is learned through interaction with others.
    - Especially in multi-national OOTW, members of different cultural background have to interact. Mutually acceptable norms of behaviour will have to be developed in the process.
    - Socialisation process
- Culture lag

  Changes in the environment or to the organisation often require adaptations in behaviour. Sometimes these changes are required or introduced so fast that an organisation hasn't had the time to the whole of its culture to adapt to the new situation, i.e,. to embed the changes in its culture. This may lead to friction.

    - E.g.1: The introduction of new technologies may change the way we work. If this is done too fast, or without thoughtful guidance it may have a disruptive effect on behaviour and thus on organisational effectiveness.

- E.g.2: Peace Keeping and War Operations each require different types of behaviours which is often quite different from the type of behaviour in the peaceful environment at home. Western armies operate on personnel rotation schedules whereby individuals change frequently from one situation to another. This may also result in culture lag causing friction.

- Sub-culture

  Within the larger set of culture, groups may develop specialised cultures, such as, e.g., distinct unit cultures.

  - Sometimes these sub-cultures may conflict over some issues with the dominant organisational or societal culture. Understanding these differences is often the first step in resolving these situations.

- Social Control.

Individual (group, organisational) members watch and correct each other if they accepted procedures of behaviour aren't followed.

- If this corrective action pattern is too strict, the group becomes rigid and is less able to adapt to new situations.

        - If it is too loose, and no culture or norms are enforced, chaos and uncertainty may rule the group.

    - Commanders Intent.

      A leader can effect the current (sub) culture of his unit by setting the example and by establishing and enforcing required procedures and behaviour.

        - Both must be synchronized, else friction will occur.
        - By action and word a leader sets the level and direction of (social) control.

    - Ethics

- Cooperability
    - Effectiveness of communication
    - Willingness to co-operate and collaborate

4. <u>Environmental factors</u>

These factors affect individual, organisational and group issues.

- Noise
- Visibility
- Temperature / humidity
- Terrain type
- Infrastructure in area of operations. (E.g. transport, communication, healthcare,

agriculture, food distribution, water, civil administration -infrastructures)

- Military support infrastructure
- Social, economic, and political situation in area of operations
- Rules of Engagement
- Ease of interaction
    - Command Post layout
    - Communication mechanisms (e.g. voice, teletype, VTC)
    - Geographic distribution of the command

Related Human Science Disciplines

This list provides an overview of the relevant scientific disciplines with the expertise to answer questions arising in the context of human and organizational issues in command and control. The list implies a rough taxonomy of disciplines only. Even though boundaries between disciplines are frequently fuzzy, an attempt was made to minimise the overlap.

1 Psychology

1.1 Individual Psychology

1.1.1 Cognitive Psychology

1.1.2 Learning Psychology

1.1.3 Action Theories

1.1.4 Differential Psychology

1.1.5 Psychometrics

1.2 Social Psychology

1.3 Clinical Psychology

2 Educational Sciences and Pedagogics

3 Sociology

3.1 Social Morphology (e.g. Social Stratification, Demography)

3.2 Sociology of Political Power (See Also Political Sciences)

3.3 Mass Communication

3.4 Sociological Methodology (Empirical Social Research)

4 Organisational Sciences

5 Economic Sciences

6 Political Sciences

6.1 Science of Domestic Politics

6.2 Science of International Relations

6.3 Political Disaster Research

7 Ergonomics, Human Factors Research

7.1 Physiology and Anthropometrics

7.2 Technical Ergonomics (Man-Machine-Interface, Workspace)

7.3 Cognitive Ergonomics (See Also Individual Psychology)

7.4 Crew Ergonomics (See Also Social Psychology)

7.5 Safety and Health Hazard Prevention

8 International Law of War, International Humanitarian Law

9 Ethics

9.1 Deontology (Theories of Ethical Norms and Values)

9.2 Theories of Ethical Practise and Morality

10 Social and Legal Philosophy

11 Cultural Anthropology

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ANNEX E

Alternate Definitions of Risk and Uncertainty

A number of different definitions of risk and uncertainty are in common use, and this can lead to confusion and misunderstanding. This COBP adopts specific working definitions of risk, uncertainty, and sensitivity; however, this annex lists a range of others for information.

Risk

Risk is defined in this COBP as the possibility of suffering harm or loss. In other words, exposure to harm or loss. This includes an opportunity loss.

Alternate definitions of risk in common use include:

- not achieving your objective;
- the likelihood of not achieving your objective;
- a threat to successful outcome;

- an assessment of the probability of failure;
- an uncertain future scenario; and
- a perception of consequential pain.

The alternate definitions may be seen as subtle variations of each other and are all equally valid. However, this very subtlety can be a source of confusion and doubt within a study unless a clear working definition is adopted.

Uncertainty

Uncertainty is defined in this COBP as an inability to determine a variable value or system state (or nature) or to predict its future evolution.

Alternate definitions of uncertainty in common use include:

- a lack of clarity in the definition of a system or variable;
- a lack of confidence in an assumption or result; and
- a lack of knowledge about a subject of interest.

All of these definitions have some validity, but this should not be allowed to cloud the thinking during C2 assessment.

Sensitivity

Sensitivity, as used in this COBP, describes a predisposition to respond strongly to a stimulus or variations in an input factor.

Alternate definitions for sensitivity in common use include:

- an indication of the importance or criticality of a feature or variable of an analysis; and
- a measure of the political profile of the subject of study.

Sensitivity, as it relates to the production of robust analysis, must be clearly defined in terms of response to stimulus rather than importance or criticality. In C2 systems many insensitive factors are critical and many sensitive ones are relatively unimportant.

ANNEX F

SAS-026 History

This revised and expanded version of the COBP for C2 assessment was developed by SAS-026 building upon the initial (1998) version of the COBP produced by SAS-002. This edition of the COBP is a synthesis of decades of expertise from various countries and hundreds of analyses. It was developed using a set of case studies and incorporates feedback from users of the initial version. Lastly, SAS-039 provided a peer review of the final draft product. Members of SAS-026 are listed below.

Dave Alberts (chair), United States

Tim Bailey, United States

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