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CHAPTER 0

EXECUTIVE SUMMARY

0.1 SUMMARY OF THE STUDY

i. A Research Study Group (RSG) on Modelling of Command and Control (C2) was established by DRG Panel 7 to develop a Code of Best Practice (COBP). The group has been considering how analysis and modelling of C2 can best be used to support decision makers in acquisitions, operational assessments (including tactics, techniques, and procedures [TTP]), and force planning. The COBP is designed for use by experienced operations analysis (OA) analysts with a background in warfare modelling and analysis, with some knowledge of, or experienced in, C2 and its analysis.

ii. Participants of the RSG were national representatives from Canada, Denmark, France, The Netherlands, Norway, Spain, Turkey, the United Kingdom, the United States, and a representative from the NATO Consultation, Command and Control Agency (NC3A).

iii. The RSG met over a period of 28 months, and has accepted contributions from national representatives as the basis for discussion. It developed a C2 analysis methodology and a COBP to implement the methodology. Although the emphasis of the COBP was on conventional warfare focused on land combat, it was developed as robustly as possible and can be extended, with some additional effort, to a variety of other arenas.

0.2 MAIN CONCLUSIONS

iv. The OA communities of NATO member nations have been increasingly asked to address C2 issues in the acquisition, operational analysis, and force structure arenas. This trend, which arises from the rapid pace of change in information technology and its impact on military affairs, will continue for the foreseeable future.

v. While complex and challenging, particularly because they involve the behaviour of humans under stress in distributed locations, meaningful analyses of C2 and C2 systems are possible. Explicit assessment of human factors and organisational issues is often a key element in the C2 analysis process.

vi. For many problems it will prove highly desirable to involve an interdisciplinary team that includes expertise in C2, modelling, and other appropriate disciplines, such as organisation theory, information technology, and human factors.

vii. The traditional tools and approaches of the OA community are essential, but they need to be enhanced and expanded to fully support successful C2 analyses. Tools need to be designed from the beginning with C2 as an integrated element. It is not sufficient to assume perfect C2 or to include it as a separate add-on module.

viii. No single measure or methodology exists that satisfactorily assesses the overall quality of C2. The crucial causal and analytic chain for C2 analyses is the linking of dimensional parameters to measures of system performance to measures of C2 effectiveness and measures of force effectiveness. The level of analytical rigor necessary to establish these links can be achieved through the associated processes of problem decomposition and measure of merit selection.

ix. Creative approaches to validation, verification, and accreditation will be essential for successful C2 analyses. The most effective approach to this issue is application of multiple tools and models to cross-check results.

x. There is a commonality of approaches in different nations with a common understanding of the issues. Analysts are applying C2 modelling to a wide range of issues, and have developed a good understanding of the criticality of C2 to proper analysis of combat outcome.

xi. Much work still needs to be done in the areas of modelling other than high intensity combat, representation of the cognitive processes in models, level of detail in the modelling of enemy forces, and the level of interactions between forces.

0.3 MAJOR RECOMMENDATIONS

xii. The RSG recommends that the Code of Best Practice be adopted by the Research and Technology Board as an acceptable standard for the evaluation of the contribution of C2 to military operations.

xiii. The RSG recommends that basic research in the modelling of C2 into a number of areas be supported. These areas include Operations Other Than War (OOTW), Information Operations (IO), and the cognitive processes involved in human decision making.

xiv. The RSG also recommends that a follow-on SAS working group be established to study the modelling of OOTW and IO.

0.4 MILITARY APPLICATIONS

xv. This COBP describes the analytical tools and techniques which will allow the study and evaluation of the contribution of C2 systems on the battlefield. This development will enable the contribution of current and new C2 technologies to military operations to be compared with other investments, thus providing information for deriving investment strategies based on the combat values of C2 systems versus other battlefield investments.

OUTLINE OF CHAPTERS

Paragraph No.

CHAPTER 1 - INTRODUCTION

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CHAPTER 1

INTRODUCTION: OVERVIEW AND SUMMARY OF KEY POINTS

1.1 INTRODUCTION

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

2. This Code Of Best Practice (COBP) offers guidance on the assessment of C2 (including C2 systems) for the purposes of supporting decision makers in acquisitions, operational assessments (including tactics, techniques, and procedures), and force planning. It is intended for use by experienced operational research analysts who are not necessarily experienced in C2 and its analysis, but have a general understanding of the C2 process. For many problems it will prove highly desirable to involve an interdisciplinary team that includes expertise in C2, modelling, and other appropriate disciplines, such as organisation theory, information technology, and human factors.

3. As the pace of change in information technology has accelerated, it has both enabled and changed C2 systems dramatically. Many nations are therefore increasingly making decisions about C2 structures, functions, processes, and systems. As this occurs, the operational analysis (OA) communities in their defence establishments are increasingly tasked to conduct systematic studies and analyses on C2 issues. Hence, more of the OA community is becoming involved in these types of research.

1.2 BRIEF HISTORY OF SAS-002 (FORMERLY RSG-19)

4. The Ad Hoc Working Group on the Impact of C3I on the Battlefield was formed by Panel 7 of the NATO Defence Research Group in 1991 to assess the state of the art in C2 analysis. Based on the recommendations of the Ad Hoc Working Group, Panel 7 constituted Research Study Group-19 (RSG-19) to address issues of methodology, measures of merit, and tools and analysis. The panel also addressed issues of improving a nation's capability to examine C2 acquisition and decision making. At the October 1995 RSG-19 planning meeting,

the group determined that the primary product of RSG-19 was to be a Code of Best Practice for assessing C2. As part of selected RSG-19 meetings, workshops would be conducted to support the development of the major sections of the COBP. Workshops were conducted on Measures of Merit (Canada), Scenario Development (Netherlands), 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.

5. 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 will be a forum for presentation and discussion of the COBP and related topics.

6. 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 after SAS-002 ends. [1] The Chairman recommended that the primary focus of the follow-on group be Operations Other Than War (OOTW), and that this group also consider Information Operations (IO) if there are sufficient time and resources. See Annex VI for a more detailed summary of the history of SAS-002.

1.3 FOCUS

7. The Research Study Group that developed this COBP emphasised conventional warfare and focused primarily on land combat. Those choices reflected both the experience of its members and the Terms of Reference by which it was chartered (See Annex IV). However, the COBP was also developed as robustly as possible, and it can be applied, with some effort, to a variety of other areas. For example, issues of combat service support, conventional air and naval operations, as well as joint and combined operations are all potential areas for extended application. Moreover, some of the measures of merit (MoM) and tools discussed in the COBP arose from, and could be applied to, selected aspects of military training. The COBP may also be extended to cover OOTW. Finally, the RSG recognised that these tools and techniques may well be directly applicable to limited aspects of IO. However, only limited

[1] In 1998, NATO reorganized its science and research activities. As a consequence, Panel 7 ceased to exist and the Studies, Analysis and Simulation (SAS) Panel was created to assume some of its responsibilities. Accordingly, RSG-19 was redesignated SAS-002.

consideration was given to IO. The group recognised that the sensitive nature of national programs in the IO area may be a barrier to further explicit examination.

8. Cost analyses were explicitly excluded as the COBP for C2 was developed. First, cost analysis is a mature discipline which experienced operational analysts already practice. Hence, C2 issues are not unique in this 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.

9. Finally, as is discussed below, C2 analysis often involves complex issues of human behaviour and organisational cultures. One facet of C2 assessment involves physics dominated problems, such as modelling propagation or communications flows. Although these issues often present unique challenges, substantial capabilities for these types of analyses already exist in all NATO countries. Hence, these problems should be manageable by experienced OA analysts and were excluded from specific consideration.

1.4 UNIQUENESS OF C2 ANALYSES AND ISSUES

10. C2 issues differ in fundamental ways from physics dominated problems. **These differences arise primarily from the fact that C2 deals with distributed teams of humans operating under stress.** That focus creates a multi-dimensional, complex analytic space. Combat involves multi-sided dynamics including friendly, adversary and other actors, action-reaction dynamics, and tightly-connected interactions among subjective elements such as organisations, cultures, morale, doctrine, training, and experience and between those subjective elements and the combat arenas. C2 issues are difficult to decompose and recompose without committing errors of logic. Moreover, the composition rules, by which the various factors that impact C2 interact, are poorly understood except in arenas that have been previously studied in detail. Finally, the C2 arena is weakly bounded, with issues that, although on initial examination appear quite finite, prove to be linked to very high-level factors. For example, tactical performance may be tied to national culture.

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

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

13. **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, and many OA studies have simply assumed perfect C2 in order to focus on other variables. This COBP is intended to assist the community in dealing with, and overcoming, the barriers to effective analysis of C2.

1.5 C2 ASSESSMENT PHILOSOPHY

14. The COBP assumes that a C2 system is intended to exercise control over its environment through either adaptive or reactive control mechanisms, or some combination of those two approaches.

15. The analysis of C2 should consider all the relevant command levels and functions involved and should investigate issues of integration across 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. Both human factors and organisational issues must be included in C2 analyses.

16. C2 analyses must 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.

17. 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 effectiveness. Modelling and other tools must be designed to support this requirement.

18. 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).

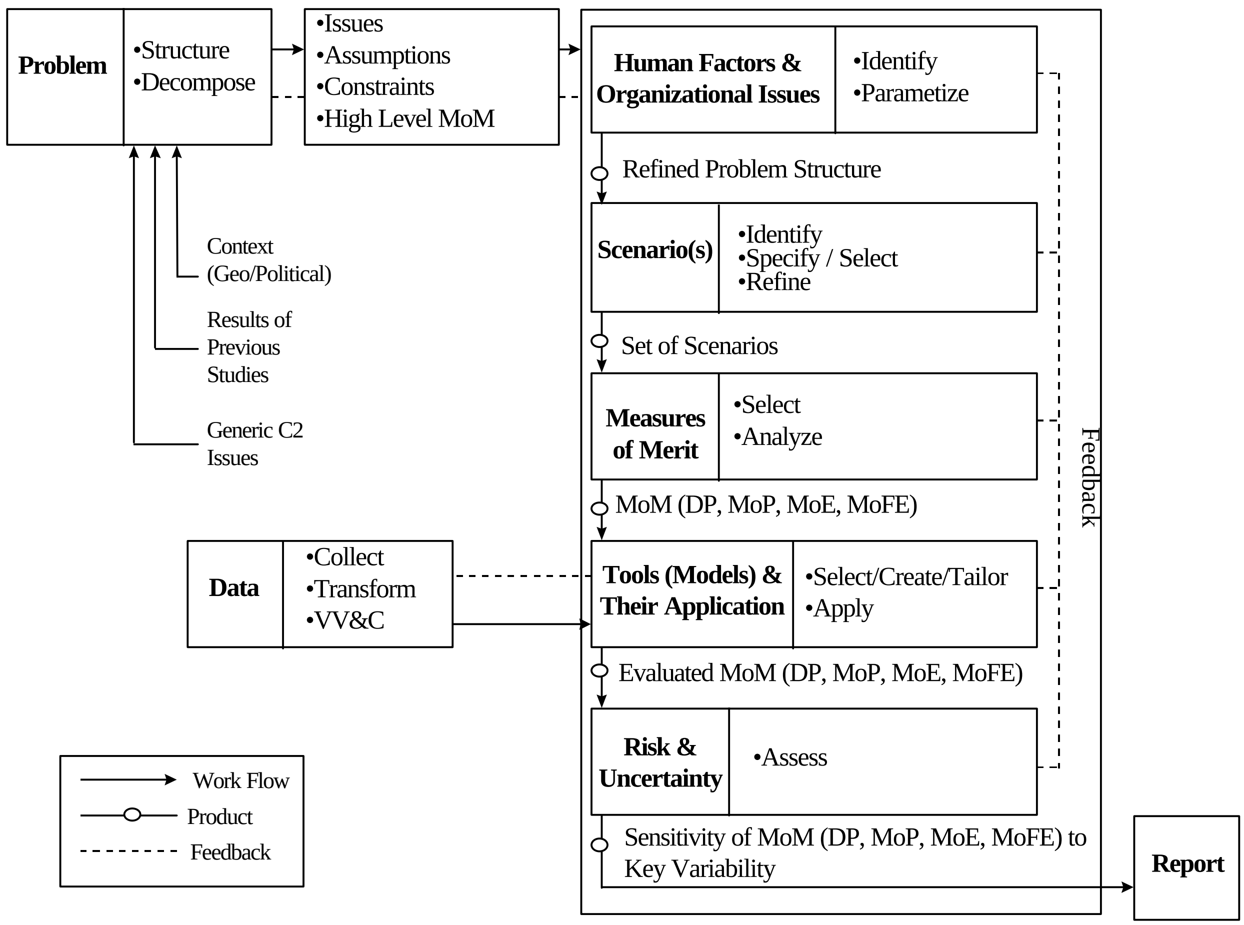
19. Finally, because the complexity of C2 and the requirements for its analysis are often underestimated by decision makers, a continuing dialogue between analysts and those decision makers is necessary both to scope properly the problem and to ensure that the analytic results are properly understood.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

20. **Changes to C2 systems will often lead to changes in tactics, techniques and procedures (TTP), doctrine or related factors, which must be considered in the analysis.**

1.6 CURRENT STATE OF PRACTICE IN C2 ANALYSIS

21. Analyses of C2 issues typically employ 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 in a much weaker state of VV&A than those 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 enable an OA analyst to conduct successful analyses.

Figure 1.1 - Recommended C2 Assessment Methodology



22. Figure 1.1, Recommended C2 Analysis Methodology, illustrates the major elements of an effective C2 assessment.

(1) In order to organise the problem properly, the analyst must consider the geo-political context of the research problem, the results of previous studies on related issues, and the generic C2 issues under analysis;

(2) The structuring of the problem should give particular consideration to framing (bounding) the analysis and decomposing the problem into its constituent elements;

(3) The explicit consideration of the potential impact of human factors and organisational issues is essential in formulating hypotheses and selecting appropriate scenarios and tools;

(4) The range of relevant scenarios in which the military activities of interest will take place should be identified, specified, and refined;

(5) The appropriate MoM need to be identified and analysed; and

(6) The processes of tool selection and application to evaluate the MoM must be executed, including assessments of risk and uncertainty present in the analysis.

23. **Note that the recommended methodology is an iterative process.** First, each major step in the analysis is linked to prior steps by a feedback loop. This reflects the fact that results or problems in the analysis may indicate a need to return and adjust prior steps. Second, the experience of RSG members suggests that successful C2 analyses are often iterative in the largest sense. That is, at least two cycles are often necessary. In the first such cycle, the analytical goal is to scope and focus the analysis. This cycle involves a minimal amount of modelling or computation. This first iteration often helps determine appropriate boundaries for the problem, benefits and drawbacks of the alternatives under analysis, appropriate boundaries for the scenario space, high-level MoM, tool availability and requirements, data requirements and availability, and time and resources available and necessary for the analysis.

24. The completion of the first cycle will typically enable the analyst to work much more effectively in the practical execution of the research and in the interpretation of the results. The first cycle will also often provide important insights and preliminary assessments that can be used to ensure successful dialogue with the decision maker or other clients.

25. Once the first cycle is complete, the analyst uses the second cycle, and any additional cycles, to complete a more focused and deeper analysis based on the parameters established in the first cycle.

1.7 CHAPTER MAPPING

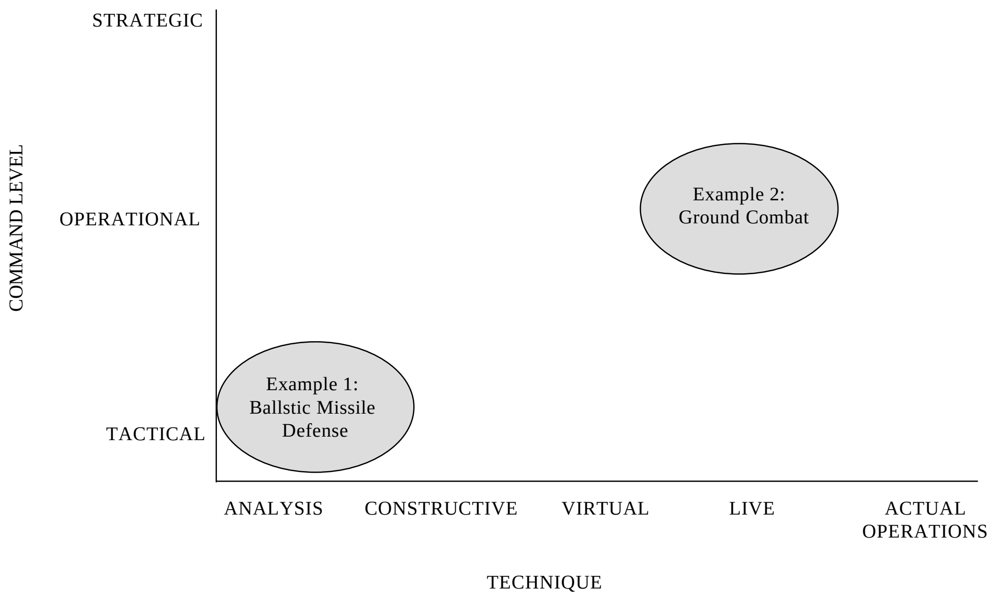
26. The organisation of the COBP is driven by the recommended C2 analysis methodology. Problem structuring is handled in this chapter. Human and organisational factors are covered in Chapter 2; scenario specification and selection are discussed in Chapter 3; measure of merit selection is treated in Chapter 4; tools (models) and their application are dealt with in Chapter 5; conclusions and recommendations resulting from the RSG are presented in Chapter 6.

27. The RSG has introduced two examples in order to avoid an abstract and potentially sterile discussion. These two examples have been chosen to represent two extremes of the envelope of possible studies. As shown in Figure 1.2, this envelope extends across the various levels of the command structure, from tactical to strategic in one dimension, and from analytic models to simulations, field trials and actual operations in the other dimension. The first example is at the extreme of a problem at the tactical level which can be expressed in closed form, while the second example is at the other extreme of a problem at the operational/strategic level, using a mix of simulation and field trials. In general, any other problem is likely to fall between these extremes.

1.8 PROBLEM STRUCTURE

28. Often, C2 issues are presented to the OA analyst in the context of some specific geo-political situation. That might take the form of defence guidance, approved scenarios, or geo-political environments within which the defence establishment anticipates particular missions. In other cases, particularly C2 acquisition issues, the geo-political context may not be explicitly identified, but rather left as a part of the analyst's responsibility. In either case, the analysts must ensure an understanding of the mission(s), objective(s), and threat(s) in the analysis. Not only adversary issues, but also the structure and character of friendly forces, military chain of command, and other actors (such as refugees, neutral parties, and coalition partners) must be identified.

Figure 1.2 - Envelope Of Possible Studies



29. The C2 analyst should also look for previous studies and analyses. Most issues have been the subject of prior research. Past work can be a valuable source of ideas, data, information, and insight. Moreover, careful review of earlier work will often help the analyst identify pitfalls and analytic challenges.

30. Finally, the initial work should seek to identify the "generic" C2 issues contained within the terms of reference for the study. For example, identification of key C2 systems, doctrine, TTP, structures, and key assumptions (e.g., system performance parameters) are essential if the problem is to be structured properly.

31. Problem structuring involves decomposition of the analytic problem into appropriate dimensions such as structures, functions, mission areas, command levels, and C2 systems. Some decompositions can be much more readily analysed than others. Appropriate

decompositions will enable the analysis to focus on key issues. At the same time, the analyst must be aware that inappropriate decomposition may make it impossible to answer questions about overall performance or effectiveness. Appropriate decomposition may also be impacted by data availability. **The key issue in decomposition is to subdivide the problem into affected segments that are amenable both to meaningful analysis and to meaningful synthesis.** That is, the elements used to perform focused analyses of the key components of the problem must be reassembled to provide a coherent knowledge about the original, larger problem. Hence, selecting the appropriate decompositions and ensuring the integrity of the analytic processes by avoiding inappropriate decompositions are important guidelines.

32. As with the other major elements of the analysis, results of problem structuring should be communicated to the decision maker and discussed to ensure responsiveness to both the formal and informal tasking. The outputs of problem structuring are a clear articulation of the issues, the key assumptions, the intended scope and constraints under consideration, and the development of high level measures of merit.

1.9 HUMAN FACTORS AND ORGANISATIONAL ISSUES

33. C2 is distinguished largely by the human dimension. C2 analyses must often deal with these "soft" factors because more of the benefits from new C2 technologies, especially information technologies, can only be obtained through organisational changes or changes in the training and experience of key personnel.

34. Human factors include three major categories:

(1) Human performance;

(2) Quality of decision maker; and

(3) Command style.

35. Human performance aspects mainly deal with stress and fatigue, which are manageable by human factors experts. The quality of decision maker is more difficult to take into account, since approved doctrine is not always used, and complex decision making processes are very difficult to model. It is possible, however, to design rules or algorithms for some decision processes when the possible solutions are limited. Complex decision making often requires the use of "human in the loop" techniques. Modelling of command styles may

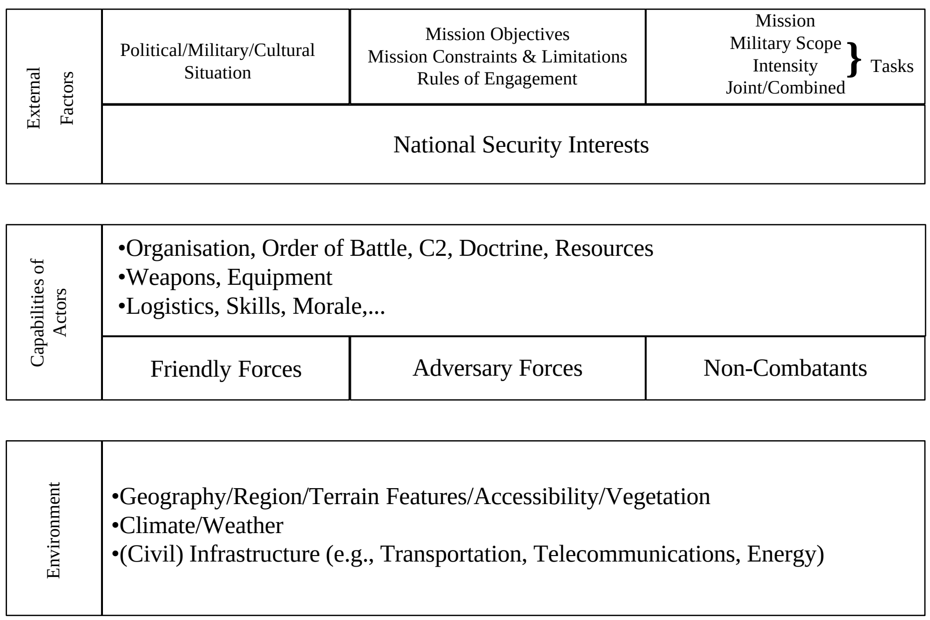
introduce unwarranted complexity for the analysis, however a typology of the various command styles should be defined in order to account for their impact on the problem.

36. Organisational issues deal with relationships among groups of individuals (organisations), including structure, function, capacity, and roles. The analytical process divides the organisational issues into their constituent components and allows the analyst to develop hypotheses on the effect of these issues. The analyst should identify the relevant organisational factors and identify those parameters that are being manipulated in order to determine if the necessary causal mechanisms are present to verify the predicted effect.

1.10 SCENARIO SPECIFICATION AND SELECTION

37. Three major steps are involved in the scenario specification and selection process: identification, specification, and refinement of scenarios. The first step is to identify the range of possible scenarios consistent with the problem structure and relevant human factors and to characterise the set of key factors and assumptions. Figure 1.3, The Scenario Framework, provides a menu for organising this process. There are three key factors in this process: external developments, military capabilities, and environment. From the space of possibilities, the analysts' goal is to identify those key or unique factors that must be included. For example, if the issue involves coalitions, both own and allied forces must be considered. Some experienced analysts prefer to begin with an unbounded scenario set that essentially uses continua to define the range of interests. Others have found that they can manage complexity better by specifying a particular set of scenarios of interest. **In either case, multiple scenarios need to be considered**, partly to ensure that the problem is fully addressed and partly to prevent inappropriate detailed analysis of a single, perhaps anomalous, situation. Modern combat is simply too complex to restrict C2 analysis to a single, rigid set of assumptions. Finally, the analyst checks the initial set of scenarios to ensure that they cover the range of C2 issues and elements of the problem as well as potential changes in the C2 environment as identified in the decomposition process.

Figure 1.3 - The Scenario Framework



38. The initial range of scenarios will typically be too large for reasonable analysis. Hence the second step is to tailor the scenario space and to focus the analysis on the segments of the scenario space of importance to the analyst. This is best done by adhering to the following tenets. First, ensure that the scenarios require appropriate information flows and decision making between and among the entities of interest. Second, match the information states of the entities to those of interest in the problem. This allows selection of the most important segments of the scenario space. Finally, consider the scenario's demands on the entities for dynamic actions and reactions. Some scenarios should be reserved for sensitivity testing, while others should be specified for in-depth work.

39. The final step in scenario refinement is driven by the C2 issues identified in the problem structure and decomposition(s). Scenarios that do not make unique demands in the C2 arena can be eliminated or removed from the analysis process, while those that appear to drive the C2 performance and effectiveness issues should be the major focus. **Note that single scenario selection is almost always an error when examining C2 issues**, because the complexity of the C2 arena can rarely, if ever, be captured in a single situation.

1.11 SELECTION OF MEASURES OF MERIT

40. This step of the strategy seeks to select the MoM which best illuminate the decision problem at hand. After reviewing a variety of approaches and tools, **the RSG concluded that no single measure exists that satisfactorily allows the assessment of either the overall effectiveness of C2 or the performance of C2 systems**. A multilevel hierarchy spanning dimensions of performance, measures of system performance, measures of C2 effectiveness, and measures of force effectiveness need to be considered.

41. The selection of MoM should be based primarily on the problem decomposition and issue selection developed earlier in the analysis. The rationale underlying the scenario specification may be an important source of insight into the measures needed. However, the linkages between measures, within and between the levels of the measurement hierarchy are the key to successful selection. If these relationships are thought through, the results of the analysis will be much easier to understand and interpret for non-technical audiences. The selection of MoM, like the other key steps in the C2 methodology, should also be discussed with the decision makers. Their acceptance of this formulation is the beginning of their acceptance of the results of the project. The Code of Best Practice has adapted the Military Operations Research Society (MORS) hierarchy with minor modifications as the basis for selecting MoM. Figure 1.4 depicts the relationships between MoM and the environment, forces, C2, and subsystems.

42. As the basis for its typology, the MORS Task Force developed a four level hierarchy of measures that has proven useful over the past two decades. They recognise:

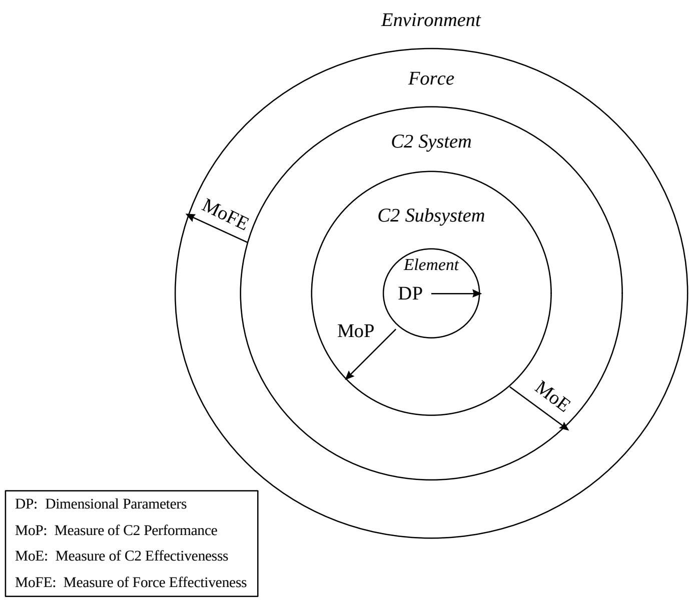
(1) Measures of Force Effectiveness (MoFE) which focus on how a force performs its mission or the degree to which it meets its objectives. Examples include territory gained or lost, rate of advance, combat loss ratios, and casualty ratios.

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

(3) Measures of C2 System Performance (MoP) which focus on internal system structure, characteristics, and behaviour. Performance measures of a system's behaviour may be reduced to measures based on time, accuracy, capacity or a combination that may be interdependent.

(4) Dimensional Parameters (DP) which are the properties or characteristic inherent in the physical C2 systems. Examples include bandwidth of communications linkages, signal to noise ratios, component size, number and variety of wavebands, and luminosity of display screens in command centres.

Figure 1.4 - Relationships Among Classes of Measures of Merit



43. The boundaries between the MoM depicted in Figure 1.4 are necessarily oversimplified. The linkages among the MoE are often much more complex. It can be difficult to discern the linkages between the levels of MoM unless the research design is crafted to capture them.

1.12 TOOLS (MODELS), THEIR APPLICATION, AND MOM EVALUATION

44. The RSG felt strongly that models and simulations are the key tools by which OA analysts can contribute to the study of C2 issues. Hence Chapter 5 is entitled “Tools (Models) and Their Application,” though it includes “all tools (models, simulations, or other quantitative and qualitative techniques) that can be used” to examine C2 issues. It includes live, virtual, and constructive modelling and simulation approaches. While the primary focus of the COBP is on constructive modelling and on how best to enhance and apply it to the analysis of C2

impacts on battle outcome, the logic and arguments presented apply across the range of C2 analytic tools.

45. The RSG found that model makers have in the past tended to assume perfect C2, thereby excluding its impact from their analyses. When included, as has increasingly been the trend over the past few years, the primary method has been to add C2 elements on to current models, which has generally meant incomplete or inadequate treatment. While newer models are beginning to include C2 as an integral piece, this arena remains relatively new and has few documented successes. Although recent progress appears promising, continued developmental efforts are essential.

46. The selection of models should be based on the following general guidelines, bearing in mind that a complete analysis will often involve the use of multiple models that may employ different approaches and draw from different databases:

(1) The selected model should capture the essential elements of the C2 processes of interest and must allow quantification of the MoM selected.

(2) The evaluation plan will often include an iterative process of model-test-model, which implies assessing the time and resource requirements for model application. Different research teams have used widely varying “tests” in this same general process. A few seek to approach controlled experimentation, some rely purely on models, others wargame or use loosely controlled interactions with “human in the loop.” The key is to expose the model to some context that will help the research team in identifying its strengths, weaknesses and opportunities for improvement.

(3) Model selection entails several critical choices:

(a) Stochastic vs. deterministic;

(b) Representation of human behaviour: rule based, algorithmic, or “human in the loop”;

(c) Homogenous models versus hierarchy/federations;

(d) Constructive, live or virtual;

(e) Representation of adversaries, including their C2 processes and systems[2]; and,

(f) Data availability.

(4) The status of VV&A for each model under consideration and VV&C for each database under consideration must be addressed.

(5) Consideration must be given to the need for sensitivity analyses on assumptions, data, and parameters.

47. If no existing model is adequate in terms of these requirements, the team should consider whether to modify existing models or design and build new ones.

48. As Table 1.1 indicates, the sources of data, parameters, and tools vary widely in the time required to develop them, resources needed, their explicit consideration of C2, and the credibility of the results they produce. Unfortunately, the most credible sources are often the most costly or the least available, while those cost effective sources often lack credibility. The C2 analyst will need to examine the structure of the problem under analysis, as well as previous studies and available tools to identify the proper tools or mix of tools necessary for analysis. **A mix of tools is often the best choice.**

49. The Research Study Group found that C2 modelling would be at its best, if eight key requirements were satisfied, **from both friendly and adversary perspectives**.

(1) Represent information as a commodity;

(2) Represent the realistic flow of information around the battlefield;

(3) Represent the collection of information from multiple sources and the tasking of information collection assets;

(4) Represent the processing of information;

(5) Represent C2 systems as entities on the battlefield;

[2] Recent interest in issues such as "information superiority" and "information dominance" emphasises the importance of representing friendly and adversary C2 processes and systems.

(6) Represent unit perceptions built, updated, and validated from the information available to the unit through its information systems;

(7) Represent the commander's decision based on the unit's perception of the battlefield; and,

(8) Represent information operations.

Table 1.1 - Treatment of Assessment Techniques

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

*CPX - Command Post Exercise
*FTX - Field Training Exercise

1.13 EXPERIMENTAL DESIGN

50. The experimental or analytical design for C2 analysis is a synthesis of the scenario space, MoM, and tools selected. This is captured in a "run matrix" or "experimental design" matrix that includes the order of execution, is designed to compensate for the level of learning

expected (if the tool involves live operators), and the number of runs necessary. This experimental design matrix bounds the analysis, but may need to be changed as results are reviewed. In particular, while the ideal parameters are independent, the correlation among parameters that typically exists in C2 problems must be considered when the run matrix is developed. For example, where intercorrelation among parameters is expected to create problems, decomposition of the problem to separate the elements of the analysis may be necessary.

51. The VV&A process will always be a challenge, whether a new model is developed or established models are being applied. The challenge of VV&A should not be ignored but dealt with directly. The “ideal” model is one that has been applied in other contexts and found to represent human behaviour and complex interactions well. Less ideal models are seen as reasonable by experts in the field, both in terms of their constituent elements and in terms of the results they generate. Clearly, the best source of validation would be high quality data from actual operators. Field trial data, which provides a favorable balance of control and “real world” circumstances, are also highly attractive. When these are not available, the ability to replicate results using different models that incorporate different assumptions and parameters at least provides some technical validity and sense that results are not simply assumption driven. This is another important reason for both employing multiple tools and models in the analysis as well as for an iterative analytic process.

52. While the experimental design and run matrix may be beyond the technical knowledge or understanding of the decision makers being supported, they represent a critical set of decisions about the analysis. Hence, the C2 analyst should review them and discuss their implications with the project’s sponsors.

53. The experimental design matrix should directly consider the data analysis process that addresses each of the C2 issues and uses the selected MoM. Failure to create this analysis plan will almost inevitably force the analyst to return to earlier stages of the process. Execution of an analysis plan is generally well within the skills and experience of OA analysts and is not treated in detail in the COBP.

1.14 ASSESSMENTS OF RISKS AND UNCERTAINTY

54. The analysis of risks and uncertainties begins with a determination of the types of uncertainties involved, including those that may arise from the scenario, the model, or the analytic process adopted (see Chapter 4 - Measures of Merit). In particular, assumptions and

limitations built into the scenario, the model, or the data structures should be considered. Representation of human decision making deserves special emphasis.

55. As in all OA research, the primary approach to assess risk and uncertainty is sensitivity analysis. The goal of the sensitivity analysis should be to establish the regions for which the results are valid and to isolate those factors that may be introducing uncertainty. 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.

56. The RSG members noted that sensitivity analysis and risk assessment in C2 analyses have often been less than thorough because of limited time and resources available and because of the complexity of the issues being examined. This is generally a mistake. **The need for, and results of, sensitivity analyses should be stressed in discussions with the decision makers.**

1.15 REPORTS

57. The form of reports delivered to customers varies widely. Senior policy makers often prefer annotated briefings. These briefings may have little or no formal or official status, but they may be very important in the decision process. Such briefings are relatively difficult to retrieve because they are often not referenced systematically. This reduces their availability to analysts working similar problems. Policy processes are often driven by summary documents or executive summaries. Here again, the availability of these summary materials may be limited precisely because they impact major policy decisions. Therefore, the results of C2 studies should normally be documented in a technical report.

58. The technical reports, documentation of modelling and analysis, and the resulting data or information bases generated in C2 analyses are potentially very valuable and should be archived and indexed to be available to other researchers. Unfortunately, processes for archiving and sharing results are seldom formal and do not exist in many research organisations.

1.16 FURTHER DEVELOPMENTS/NEW METHODS

59. The RSG membership identified a number of novel developments that may transform C2 analysis over time. First, as experience, knowledge, and confidence in C2 analysis accumulates, potential is created for greater interaction among analysts and for the

creation of a stronger professional community. Second, as the role of information technology continues to grow in military systems, C2 processes will tend to become a cornerstone of future combat models rather than an add-on to existing models. The policy of developing C2 or C2 based models has already been adopted by some nations and will be increasingly common (See Annex VIII).

60. Within the area of scenario specification and selection, a strong trend has emerged that emphasises the variety of issues under study and factors that can drive the results of the analysis. While this trend requires more work to complete the analysis, it also ensures much more robust results. Moreover, as C2 and C2-based models become generally available, the cost of exploring the range of relevant scenarios and the difficulty of interpreting the results of their analysis will decline dramatically.

61. In the area of measures of effectiveness, OOTW offers a challenge to traditional methods of developing MoM. While not a principal focus for the Code of Best Practice, OOTW are missions where C2 analyses are becoming important. Traditional MoE and MoFE such as loss exchange ratios, combat effectiveness, or duration of the campaign are not always applicable to OOTW. In such operations, wherein military forces may play important roles, political concerns may limit the scope of imposition of solutions. Public and political pressures may result in shifts in the selection of criteria for MoM. Chapter 4 briefly discusses these concerns and provides some candidate measures for coping with OOTW analysis.

62. Modelling is also undergoing profound changes based on the increasing availability of computing power and a variety of nations' emphasis on modelling as a cost effective way to develop knowledge and support decision making. Among the most important new developments are:

(1) Exploiting recent advances in mathematics to create fast running models capable of reflecting complexity theory and similar concepts;

(2) Increasing use of model federations, either in the form of hierarchies or through the use of real time interfaces;

(3) Agent-oriented modelling;

(4) Linking performance modelling to effectiveness models;

(5) Developing and employing models that scan scenario space rapidly and systematically;

(6) Improved modelling of the decision making process;

(7) Algorithms that promise to capture intent, headquarters processes, “recognised pictures”; and

(8) Models of reasoning based on mission type.

63. Taken together, these developments indicate that the C2 analysis field may evolve rapidly. However, the RSG believes that the C2 analysis approach articulated here will remain relevant while these developments occur.

1.17 PRACTICAL EXAMPLE - THEATER/TACTICAL C2 ANALYSIS

64. To illustrate the major features of the COBP, the following example provides a bounding case of a theatre/tactical C2 issue where a preliminary assessment can be performed employing simple analytical tools. The example explores the appropriate balance between C2 and a weapons system to support defence against tactical ballistic missiles (TBMs).

1.17.1 Problem

65. A number of nations are in the process of developing TBMs that could hold at risk key friendly assets (e.g., airfields, key C2 nodes). There are several responses to that threat that high level decision makers can pursue. At the lowest level of difficulty, they can elect to develop and field a C2 system and process that would focus on providing timely warning of an attack and an estimate of the likely aim point(s) so that threatened targets can take defensive action (e.g., scrambling aircraft from a targeted air base). At the next level of difficulty, decision makers could elect to acquire and field a surface-to-air missile (SAM) system, with an appropriate C2 system, to intercept incoming TBMs to defend selected high value assets. Ultimately, the goal could be to extend the ability of the friendly C2-weapon system mix to provide effective defence-in-depth over broad friendly areas.

66. For the purposes of this example, an assessment will be made of the capability objectives for the range of a warning sensor and the processing delays for a C2 system that are appropriate for an effective defence of selected military targets against TBMs. This assessment involves addressing a set of subordinate issues; e.g.,

(1) At what range must the warning sensor be able to detect and track launched missiles in order to intercept them with high probability?

(2) What is the allowable reaction time of the C2 system to acquire information, process it, and disseminate results/orders to subordinate SAMs?

1.17.2 Human Factors & Organisational Issues

67. In subsequent cycles of the analysis, it would be appropriate to address related issues of organisation (e.g., how should the key functions of warning, threat evaluation, and weapon assessment be distributed throughout the C2 system) and human factors (e.g., how should relevant information be displayed to the operators). In the initial analyses, however, these issues can be treated by assumption.

1.17.3 Scenario(s)

68. As a foundation for the analysis, it is necessary to identify key factors in three broad categories: external factors (nature of the mission), capabilities factors (adversary and friendly), and environment. For the purposes of this example, it will be assumed that the adversary is seeking to use the TBMs to place key deployed friendly resources at risk to deter, or defeat, a rapid response force that was projected into the region. The objective of the friendly C2–weapon mix is to protect selected high value military assets by locating SAMs with them to intercept these TBMs at keep-out ranges that would result in a high probability of friend1y assets survivability.

69. To characterise the adversary TBMs, information is needed on their range, dynamics (e.g., velocity), use of penetration aids, and the minimum range at which they must be engaged to counter them effectively (e.g., prior to deployment of a dispenser or at sufficient range to minimise collateral damage if the TBM employs salvage fusing). In addition, an appropriate scenario must call out which friendly assets the adversary would target and how many TBMs the adversary would target against them. For the purposes of this illustrative example, it will be assumed that each defended high valued friendly asset is targeted by a single TBM; that the TBM does not employ penetration aids and can be characterised by a constant velocity, VH; and that the minimum safe keep out range is RK. It will be assumed, however, that the precise values of VH and RK are not known, although intelligence sources have provided a range of likely values.

70. To characterise key friendly forces, it is assumed that key high valued assets are defended by co-located SAMs that would be launched upon detection, tracking, discrimination, and direction by the supporting C2 system. For illustrative purposes, it will be assumed that the SAM is characterised by a constant velocity, VF, and maximum effective range, RF. For simplicity, it will be assumed that friendly firing doctrine calls for launching a single missile to counter an incoming TBM.

71. From an environmental perspective, an important discriminant is whether the adversary TBM is capable of carrying a weapon of mass destruction. This capability will have a dramatic impact on the environment in which the friendly C2-weapon mix must function (e.g., be resistant to effects such as electromagnetic pulse (EMP), blast, and scintillation in a nuclear environment).

72. Even for this greatly simplified problem, it can be seen that a single scenario is inadequate. As a minimum, it is necessary to consider a set of scenarios that subsume the intelligence community's estimated bounds on TBM velocity, VH, and minimum safe keep out range, RK. These values could, in fact, vary over time as the adversary enhances his TBM system.

1.17.4 Measures of Merit

73. A family of MoM are required to characterise the problem. At the MoFE level, an appropriate measure would be the probability that the SAM is able to intercept successfully the TBM at, or before, it reaches the minimum keep-out range, RK. Similarly , a second useful MoFE is the probability that the high value asset co-located with the SAM is able to survive the adversary's targeting strategy.

74. At the MoE level, several key measures include the range at which the warning sensor is capable of providing warning of a launched TBM (or, conversely, the amount of warning time that it provides to the SAM) and the characteristic delay that elapses, due to C2 processing, between TBM warning and SAM launch. Although this simple formulation has not addressed the issue of the accuracy of the tracking systems associated with the warning and SAM systems, a frequently used measure deals with the probability that the SAM can successfully reacquire the TBM track developed by the warning system.

75. At the MoP level, there are a host of measures that are frequently used to characterise key functions that the C2 system must perform (e.g., the probability that the warning system can successfully initiate and maintain a track on a TBM; the probability that the C2 system can successfully discriminate between high explosive warheads and decoys).

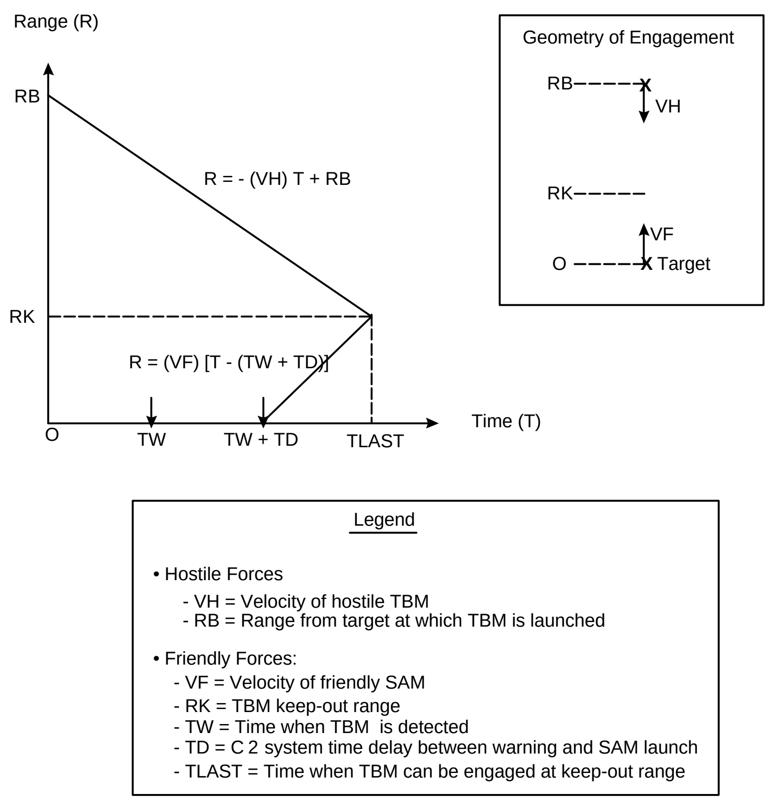
76. Finally, the prior section has identified several of the critical DPs for the adversary system (e.g., VH) and the friendly system (e.g., VF).

1.17.5 Tools and Their Application

77. The illustrative problem has been designed so that an extremely simple, deterministic model can be used to establish technical capability objectives for the warning sensor range and the associated maximum allowable processing time by the C2 system.

78. Figure 1.5 characterises the time lines for the incoming TBM and the defending SAM, assuming that both move at constant velocity. The figure identifies the key parameters characterising the adversary and friendly systems. These linear equations can be solved easily to establish the allowable values of warning range (and associated warning time) and C2 time delay. For simplicity, it is assumed that the SAM has a probability of kill (Pk) equal to 1.0 if it engages the TBM before it reaches the keep-out range.

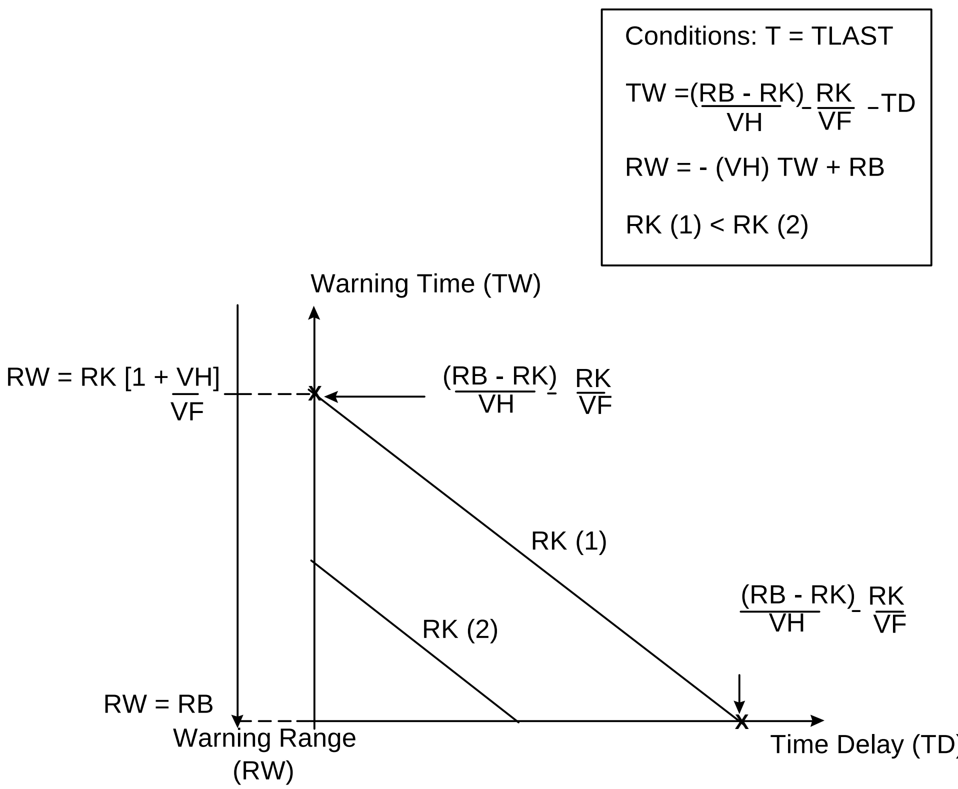
Figure 1.5. Illustrative Time Line for TBM Engagement



1.17.6 Sensitivity Analyses

79. Figure 1.6 depicts feasible solution spaces for hypothetical values of adversary and friendly parameters, for bounding values of the TBM keep-out range.

Figure 1.6 - Illustrative Trade-Offs in Sensor and C2 System Capability Objectives



80. This simplified analysis can be extended to consider alternative geometries, more complex system dynamics, and more detailed C2 system processes. However, to treat more realistic, non-linear dynamics and stochastic features (e.g., Pk<1 for a realistic intercept of the TBM), it would be necessary to employ more complicated models and simulations. Similarly, it would require the use of virtual M&S to address credibly the impact of distributed teams of operators under stress, including delays arising from human performance issues or alternative ways of distributing the information across organisations.

1.17.7 Reporting

81. This type of problem would most likely be initially reported in the form of an annotated briefing. That briefing would be modified based on feedback from senior reviewers (a "Red Team") and the decision makers who received it. The analyses should also:

(1) Be published (to the extent classification issues permit) to encourage peer review and enable future research to build on the results; and

(2) Be archived so that the model(s), data, and sensitivity analyses are available for further uses on related topics.

1.17.8 Insights from First Practical Example

82. This simple characterisation and analysis of the TBM problem provides an illustration of a potential initial cycle of a contemporary, critical C2 issue. In this instance preliminary estimates of technical capability objectives for aggregate warning and C2 system performance, were derived using a simple conceptual model. Note that in the example, trade-offs could be made between the capability objectives for the warning sensor range and the maximum allowed C2 system processing time, depending on factors such as technological risk and cost. Ultimately, more sophisticated evaluation tools would be required to explore issues that were demonstrated to be critical in successive cycles of analyses.

1.18 PRACTICAL EXAMPLE - OPERATIONAL C2 ANALYSIS

83. This example is included to illustrate the more open ended weakly bounded problems implied when major innovations are proposed in C2 systems. These are increasingly important taskings for OA communities in more countries and will continue to proliferate as information technologies transform work processes.

84. The analytic problem posed is an assessment of a new C2 technology that uses digital technology to automate the distribution and plotting of current and future information on adversary and friendly force location, status, and map-based graphics. This new system enables portrayal of future (predicted) situations including changes in the operating environment (weather, refugees, POWs, etc.). The C2 analyst has been asked to assess the contribution of this new system to improved C2.

1.18.1 Problem

85. Following the COBP, the C2 analyst first organises an inter-disciplinary team, including air/land combat modellers, and expertise in air/land C2. This team immediately conducts a search for related studies and examines the general problem to identify the specific C2 issues included. In this case, the team notes the key issues as:

(1) The increased speed of the C2 process resulting from automated updates when new information arises;

(2) The speed with which new developments in the battlespace are recognised in the command centre;

(3) The improved quality (accuracy) of the information plots based on removing humans from the process;

(4) The improved quality of planning expected as a result of the greater speed and predictive capability provided by the system; and

(5) Consideration of a larger number of courses of action as a result of this richer understanding of the military situation.

86. This restructuring “decomposes” the original problem into those elements where the analysis will focus.

1.18.2 Human Factors and Organisational Issues

87. Looking at this problem from a human factors perspective, the C2 expert expresses concern that automated plotting will reduce the quality of situation awareness among the battle staff, which has historically had a “hands on” role in recording and plotting adversary and friendly unit position and status information. The study team notes that baseline data on “human in the loop” experiments are needed to check for this phenomenon.

88. Another relevant human factor issue is whether the C2 system users will “believe” digital data more or less than traditional hand plots on maps; tests of “perceived uncertainty” are identified as significant “side analyses” but are excluded from the main analysis because the time does not exist to conduct them. The project leader notes the need to report this limit on the analytic findings.

89. The C2 expert also points out that the digitised system raises the organisational issue of data traceability, authentication and control. Some specific echelon of command and functional organisation must be assigned responsibility for fusion and updating of the digital battle space and the forecasting system. While the functional assignments are considered straight forward (i.e., G-3 for friendly unit locations, G-2 for intel) the echelon responsible is not obvious. Since the system designer assumed that Division Main would maintain all the data the C2 analysis team incorporates this as an assumption, while noting that it might be re-examined after field trials.

1.18.3 Scenario(s)

90. The digitisation study team decided that the scenario space of interest centred on the division and should, therefore, involve key higher echelon (Corps) and lower echelon (brigade and battalion) command centres and also needed to span several types of forces (own and coalition, aviation and logistics support, as well as combat forces). Discussion of peace operations resulted in a decision to exclude them since they resemble mid-level combat during their most dangerous phases and C2 speed is less important or interesting during other phases. The temporal frame proved more complex. While assessment of the speed of C2 systems and the quality of information they generated could be established quickly (over a few hours of properly selected simulation or experience,) their influence on planning and combat service support functions require a considerably longer time to play out. Hence, scenarios that cover weeks are needed. Moreover, because quality of friendly planning is a key issue, adversary forces must be given free play, so their ability to defeat these plans can be assessed.

1.18.4 Measures of Merit

91. Measures of merit were mapped against two primary issues. First, the reason for digitisation is to improve ground force performance, so the MoFE of casualty ratios, ground gained or lost, and the MoE of the ability to develop plans that accomplish military missions were adopted. The team noted that ground gained or lost would only be applicable in the high intensity combat scenario(s) because the mid-level scenario did not assume a linear fighting front.

92. Second, measures of performance were focused as closely as possible on the problem formulation. Hence (1) speed of the C2 process (time for a decision cycle), (2) time after a major change in the battle space (e.g., first use of chemical weapons, adversary initiation of counter attack, etc.) before each command centre recognised it, (3) improved

accuracy of data, (4) change in plan quality, and (5) number of alternative courses of action considered became the primary relevant MoP.

1.18.5 Tools and Their Applications

93. Several different tools and techniques were needed to analyse the digitisation system's impact. First, "human in the loop" simulations were needed to establish whether the digitisation tool changes (positively or negatively) the situation awareness of the battle staff, both at the level of factual analysis and in terms of their ability and speed in recognising situation changes. Second, using human performance parameters derived from these simulations, combat models validated for Division and Brigade were used to assess the impact of this changed information quality on military planning (within the models) and combat service support as well as to examine impacts on the MoFE. In addition, some Command Post Exercises (CPXs) were needed to establish both the baseline for C2 planning performance and the impact of digitisation on the quality of plans.

94. This approach, employing some tools and models to develop insights and parameters needed to conduct other assessments and analyses, is quite typical of the weakly bounded issues. **C2 analyses are almost never a matter of simple, single path research.** The domain is both too intricate and too complex for simplistic approaches to work.

1.18.6 Sensitivity Analyses

95. The research team chose pure simulation tools to determine the stability of the combat model results driven by human performance parameters. This is an effort to ensure that small changes in the ability of humans to recognise changing military situations are not having disproportionate effects on the performance of the simulated combat units. While large changes were anticipated, they were also expected to be continuous across the range of observed parameters, indicating that the effect is stable in the range of interest and not close to a "cusp" where discontinuities should be anticipated. Moreover, the results of the CPXs also need to be compared with the overall combat model analyses in order to see if the causal mechanisms anticipated are consistent with the dynamic interactions within and among command centres.

1.18.7 Reporting

96. Since the research design is complex and involved several different analyses, each analysis is reported independently, both in the form of annotated briefing and written research summaries. Data from each element of the analysis must also be archived. At the same time, the project team must also develop a master briefing that places each element of the overall project in context and provides decision makers with a coherent picture of the effort, its results, their meaning and their limitations. This annotated briefing must also provide the material needed to archive the research and organise it for publication and peer review.

1.18.8 Insights for the Second Practical Example

97. Weakly bounded problems will require both more attention to the human factors and organizational issues and also more time and effort to analyze. While they may include some relatively simple combat dynamics, the variety of actors and factors inherent in them will make it difficult to isolate key dynamics. However, these weakly bounded problems also offer major opportunities to develop new insights into the dynamics of key areas (such as military decision making) and their relationship to battle performance.

1.19 CONCLUSIONS

98. Conclusions and recommendations for the COBP are treated as an integrated set in the last chapter. However, some significant conclusions emerge from this introductory discussion:

(1) The OA communities of NATO member nations are being increasingly asked to address C2 issues in the acquisition, operational analysis, and force structure arenas. This trend, which arises from the rapid pace of change in information technology and its impact on military affairs, will continue for the foreseeable future.

(2) C2 is properly understood to include the enriched concepts of C3I and C4ISR.

(3) While complex and challenging, particularly because they involve the behaviour of humans under stress in distributed locations, meaningful analyses of C2 are possible.

(4) Changes to C2 systems will often lead to changes in doctrine, tactics, techniques and procedures (TTP) which must be considered in the course of the analysis.

(5) Analysis requires a systematic, step-by-step process that begins with an assessment of the benefits anticipated from C2 or related (organisational, personnel, process, etc.) changes. The process carries through the problem structuring, identification of relevant human performance and organisational factors, scenario specification, measure of merit selection, tool selection and application, including data collection, and sensitivity analysis.

(6) No single scenario is likely to be adequate. Effective analysis of C2 issues normally involves scanning a scenario space and conducting selective sensitivity analyses.

(7) No single measure or methodology exists that satisfactorily assesses the overall quality of C2. The crucial causal and analytic chain for C2 analyses is the linking of dimensional parameters to measures of system performance to measures of C2 effectiveness and measures of force effectiveness. The level of analytical rigor necessary to establish these links can be achieved through the associated processes of problem decomposition and measure of merit selection.

(8) The traditional tools and approaches of the OA community are essential, but they need to be enhanced, expanded, and combined to fully support successful C2 analyses. Tools need to be designed from the beginning with C2 as an integral element. A mix of tools is often the best choice. It is not sufficient to assume perfect C2 or to include it as a separate add-on module.

(9) Creative approaches to VV&A of tools and VV&C of data will be essential for credible C2 analyses.

(10)The most productive analytic processes applied are usually iterative and involve multiple feedback loops as well as sensitivity analyses that quantify risks and uncertainties.

(11) Reporting is highly customer dependent. There is a premium on explaining the analysis of complex systems to non-technical or partially technical audiences. The lack of systematic archiving of formal reporting increases the difficulty of replicability and denies the analyst the opportunity to refer to previous studies, most often increasing the time required to complete analyses.

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CHAPTER 2

HUMAN FACTORS AND ORGANISATIONAL ISSUES

2.1 BACKGROUND

99. Since the key difference between C2 analyses and traditional military OA applications is the need to deal with distributed teams of humans under stress and their decision making behaviour, the structuring of the problem and establishment of the research design cannot be completed without explicit consideration of both human factors and organisational issues.

100. The human factors of interest consist of three major types:

(1) Human performance questions, such as fatigue;

(2) Cognitive questions (particularly quality of decision maker), including the cognitive complexity of the issues and the capacities of the commanders or other decision makers of interest, and;

(3) Command style.

Issues related to team and small group interactions may also be important. By contrast, organisational issues deal with relationships between groups of individuals, including connectivity, roles, and organisational structures. Since both human factors and organisational issues can impact C2 performance, efficiency, and effectiveness the OA analyst must consider their impact early in the research design process. While they can be considered as part of structuring the problem, they are treated independently in the Code of Best Practice because they are very important in C2 and because they are a difficult set of factors to model.

2.2 HUMAN FACTORS

101. The first key issue is whether individual decision making and behaviour is important to the C2 processes under analysis. If the research question can be answered without considering differences between individual decision makers then the additional complexity that issue introduces should be avoided. For example, in addressing a C2 issue that deals with a simple change in connectivity (which headquarters will have which linkages to others) the behaviour of individuals may not be important to the analysis.

2.2.1 Human Performance

102. However, any time human performance is at issue, parameters 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 performance that can be traced to direct human performance issues and/or fatigue, as well as those arising from experience or training, coalition differences (for example, language), or differences in doctrine and practice between services or branches. These kinds of individual performance issues are usually modelled stochastically, which reflects their occurrence in "real" systems. The decision that human performance may vary meaningfully, therefore, will have a clear impact on the choice of models and analytic approaches.

103. Where human performance is considered to be a meaningful factor, for example, C2 within command centres when wearing protective suits and masks, 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 work flow and work rate within command centres are relevant, human performance parameters must be considered. In addition, human performance issues will have some effect on decision making – error rates increase as people become tired, overloaded people alter the way they work and the information they consider. For example, in command post exercises, US Army division and corps commanders and staffs were found to focus more on friendly information than adversary information during periods when the pace of battle was intense [2.1].

2.2.2 Human Decision Making

104. Increasingly, OA analysts are being asked to deal with issues where individual decisions are important. This represents a major challenge because the variety of human behaviours involved makes modelling decision making very difficult. Fortunately, there are some approaches that can be used to minimise these difficulties. The correct choice, however, will depend on the research issue(s).

105. In some cases the analyst is asked to assume that decision making will follow established doctrine, tactics, techniques, or procedures. In these cases, the challenge is to craft a set of rules or look up tables that reflect the existing guidance correctly. For example, Soviet doctrine provided "numerical" guidance based on the correlation of forces for when a ground force should attack, defend, call for support, etc. Hence, a model that replicated that

"correct" set of decisions would be useful for assessing simple C2 issues such as the impact of changes in connectivity or supporting relationships within the force.

106. Unfortunately, many combat models have built up sets of rules that are not driven by approved tactics or procedures, but rather by sets of subject matter experts or modelers whose rationales have neither been validated or 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 OA analyst at considerable risk of accepting false conclusions. When such models must be adopted, they should be:

(1) Explored in detail to uncover their driving assumptions; and

(2) Run in some constrained cases (overwhelming numerical advantages, precisely equal forces, differing terrain, etc.) to determine at least the face validity of their results.

Where this cannot be done, these models are best avoided when C2 analyses are performed.

107. The nature of the decisions being supported will also enable the OA analyst to make intelligent decisions about how they influence the analysis. Three useful decision types can be distinguished:

(1) Automatable decisions;

(2) Contingent decisions; and

(3) Complex decisions.

2.2.2.1 Automatable Decisions

108. Automatable decisions fall into the category of "simple decisions," or those for which the range of options is finite and known and the criteria for selecting among them are clear. Basic sensor-to-shooter decisions, for example, are simple decisions. Increasingly these kinds of decisions are being automated on the battlefield. For example missile defence problems require such rapid reaction that humans may not have the time to comprehend the situation and make a choice while the "window of opportunity" remains open.

109. Similarly, many logistics issues can be automated. Scheduling can be seen as an optimisation problem in which time, space, and priorities are traded off to generate a "best"

answer. While dynamic (elements of the transportation system are constantly changing due to weather, mechanical problems, etc.) and complex, decision making in this arena can be characterised by rules and algorithms. Models of these automatable decisions can be built relatively easily.

110. 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, the time available to make a decision may be insufficient or physical demands, such as fatigue, may become a problem and increase error rates. 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.

111. In these fully automatable decisions the assumption is that “to know is to decide.” That is, if uncertainty were adequately reduced, the correct course of action or decision would be obvious.

2.2.2.2 Contingent Decisions

112. The next level of decision making 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 battlespace developments and new information 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 decision making.”

113. In most cases the lack of clear, precise knowledge is not avoidable. 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 did select a main attack option.

114. 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 of this type are essentially hypothesis testing

models that align information about the battlespace against a finite set of alternative futures and perform probability calculations to determine when the commander has enough confidence to act [2.2] [2.3].

2.2.2.3 Complex Decisions

115. Finally, "complex" decisions are very difficult to model. These require the decision making system to not only recognise when a decision needs to be made, but also:

(1) Identify the relevant set of options;

(2) Specify the criteria by which they will be judged; and

(3) Determine when the decision would 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 broad courses of action. 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 has been completed in the UK [2.4] [2.5] that may prove useful in the long term, but practical efforts in representing the decision making process in fast running constructive simulation models and achieving reliable results are thus far limited to a few carefully selected issues.

2.2.3 Quality of Decision Maker

116. Modellers are also challenged by the idea of different qualities of decision makers. When models are developed, however, they make explicit or implicit assumptions about the qualities of the commanders whose decisions are represented. Military commanders vary in their capabilities. C2 analysts looking at issues where decision making performance may make a difference must either make assumptions about this attribute or else allow for these differences within the model.

117. Four different levels or qualities can be distinguished. In most military systems those with more experience are expected to rank higher on these scales, but experience is only one factor contributing to development of decision making capability.

(1) Routinizers know the doctrine but do not have a complete understanding of the rationale that underlies it and will largely implement the elements of it in isolation from one another. Systems where this skill level dominates will be prone to uncoordinated actions. Military systems dominated by individuals who are well trained, but lack operational experience, tend to work at this level.

(2) Analysers have an integrated grasp of the doctrinal system and will treat the system as a holistic enterprise. Connections get made so that the battlespace is synchronised, but often in a rigid way. Because systems dominated by analysers are tightly coupled, they often lack the flexibility to overcome the fog and friction of war. Hence, they become prone to deception, deep strikes or other innovative types of attacks, and are prone to "jams" (traffic jams in their rear areas, unnecessarily large attacks by fire that are inefficient in the larger operation, bottlenecks when unanticipated rapid manoeuvre is necessary, etc.). In essence, these systems emphasise the "control" aspects of C2 and thereby tend to generate brittle plans. Military organisations that have experience in exercises or small operations and are asked to undertake larger real world mission are often dominated by leaders with this level of decision making skill.

(3) Synthesisers represent the practical state of the art for a professional military force. The battlespace is understood as a multi-dimensional space that is linked from its most forward elements to the rear areas from which forces are generated and sustained. More importantly, synthesised decision making includes the capacity to look ahead and foresee vulnerabilities, potential problems, or opportunities. Systems dominated by synthesisers can undertake rich transactional agendas with success. Experienced forces, such as those which fought Desert Storm, will typically be dominated by synthesisers. However, this level of expertise is difficult to maintain over time unless the forces experience a high level of operating tempo. Models that assume synthesised decision making will often overstate the capability of the available commanders.

(4) The fourth category, the creator, is rare and should not be assumed by modellers or C2 analysts. These are the Gustavus Adolphus, Napoleons, and Jacksons who see contemporary warfare in depth and understand the dynamics that drive it. Because their vision is greater than those of their adversaries, they innovate in ways that transform the battlespace to give their forces decisive advantages.

118. Elliot Jaques' [2.6] work on bureaucracies in industrial societies distinguishes eight different levels of managerial skill and should be the standard reference for those seeking to build in different levels of decision makers in models. Extensions of that work by Deutsch and Hayes [2.7] [2.8] have explored its implications in military organisations.

2.2.4 Command Style

119. C2 analysts often encounter the argument that decision making 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, like any other, if the analyst is able to develop a clear concept of the alternative command styles that must be recognised and their consequences for military decision making.

120. For example, some of the attributes meant when command style is discussed are captured in the four levels of decision maker quality discussed above. They are really differences in the background and training of commanders that impact on the richness of their understanding of the military situation and their capacity to influence it.

121. 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. In a very real sense, the classic centralised commander imposes his style on the C2 process and impacts key organisational issues as well as decision style.

122. 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.

123. 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, OA analysts will need to create and model variables that represent this factor.

124. 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, 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 northeast into the valley) and supporting detail (forces available, rough timetable keyed to the objectives, etc.), 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 battle management) will vary greatly depending on the commander’s style on this dimension. National doctrine and practice may also influence this factor.

125. Other topologies of command styles are, of course, possible and may be more relevant to particular C2 analyses. Human factors experts (such as 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, they should only be examined because they appear to be necessary to answer the analytic question(s) of interest. Otherwise they tend to introduce a level of complexity that may confound the other analyses underway.

2.2.5 Relationships between Human Factors and Organisational Issues

126. All elements of the C2 system are ultimately related to one another. The linkage between human factors 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.

2.3 ORGANISATIONAL ISSUES

127. Organisation is a serious subject in military analyses. For centuries the military has stood for clear and 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 [2.9]. Fortunately, military organisational issues are driven by a fairly small and finite list of principles. OA analysts asked to work on C2 issues can use the known list of factors as a check list to determine whether they need to build organisational matters into their research designs.

2.3.1 How Do Organisations Differ?

128. The key ways military organisations differ are best understood as differences in structure, function, and capacity. These three categories exhaust the types of change or innovation that can be introduced in C2 organisation and can be used to guide analysts when organising a problem. Structural differences include:

(1) The number of echelons or layers in the command structure;

(2) The span of control for nodes in the command structure;

(3) The pattern of linkages between those nodes (hierarchical, spokes of a wheel, multi-connected, networked, etc.); and

(4) Permanent versus transitory organisational relationship.

Functional differences include:

(1) The distribution of responsibility (where in the system are difference activities located (intelligence, logistics, command, etc.));

(2) The distribution of authority (ideally co-located with responsibility);

(3) The distribution of information;

(4) 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,

(5) Degree of ambiguity in command relationship.

Differences in capacity include:

(1) Differences in personnel (quality, training, experience);

(2) Differences in communications systems and architectures;

(3) Differences in information processing systems and architectures; and

(4) Differences in field training and combat experience.

129. All these dimensions can be modelled, some more easily than others. However, the analysts' challenge is to identify those organisational factors that are relevant to the C2 analyses underway. This issue must also be addressed in the full knowledge that more than one organisational factor may be changing. For example, the decision to wipe out 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 [2.10]. Similar effects can be expected when coalition operations involve ad hoc members.

2.3.2 How Should OA Analysts Treat Organisational Issues?

130. 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 study team. Review of

organisational issues is treated in a two step process, guided by an hypothesis testing logic. The first review should simply look to see whether any organisational variable is being manipulated directly. For example, a decision to move from warfare domain task forces (land warfare with one commander, air warfare with another, each of whom reports directly to a joint commander) to mission tailored task forces where air and land units plan, co-ordinate, and work together directly would be seen as a direct manipulation of organisational factors and should be studied as such. The second review, a search for indirect impacts of organisational factors, may be more difficult and will require that the project team use the list of possible factors as a checklist and think through whether they may be altered in a propositional (if...then) logic. An analyst who 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 rigor.

131. 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 decision making must also include the negative features (demands for more time from already overburdened staffs and slower decision making) in their C2 models.

2.3.3 Roles

132. 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 (e.g. G-1, 2, 3 and 4) 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.

133. Roles can be used to capture "syndromes" or sets of related attributes within a C2 system. For example, an object oriented program might have the different functional organisations and their leaders defined as having different attributes that reflect their decision making 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 [2.10].

2.4 INTEGRATED ANALYSES

134. Because the issues arising from human and organisational factors are so complex and so tightly coupled, C2 analysts 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 (hopefully more elegant), which can then be augmented by sensitivity analyses and analytic excursions to ensure that the problem has been fully and properly understood.

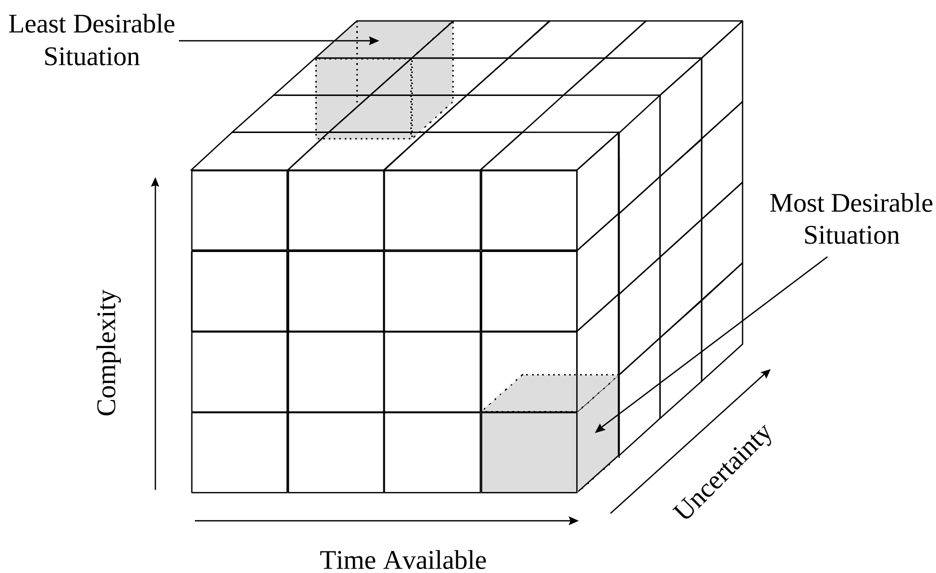
135. For example, Figure 2.1 has been used to illustrate the relationship between the time available to make a decision, the complexity of the decision itself, and the uncertainty of the information available about the situation. These three factors also reflect the risk or opportunity inherent in a 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.

136. 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.

137. 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 [2.1] suggests that when these conditions exist the decision maker (military commander) has no choice except to use “best professional judgement” to match the battlespace situation to some class of well understood military situations and act accordingly. However, decision making 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 2.1 - Relationships Among Decision Maker Drivers



138. 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 [2.11] analysis of C2 defines it as a search for greater certainty.

139. This cube also emphasises a less than well understood dimension of C2 systems and the decision making they imply. That dimension that is the key is not the time available to make a decision, nor even the perception of that time, but 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 battle is faster, decisions must be, almost by definition, reactive. The commander who is capable of making decisions that transform the battle from a reactive one into a proactive one is rare and enjoys vision not only about what is but also about what is possible. In other language, such commanders are synthesisers.

140. This key relationship (pace of battle to speed of the C2 system) is the driving force behind the OODA loop (Observe, Orient, Decide, Act) 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 the Measures of Merit chapter in detail, multiple dimensions of performance need to be analysed whenever C2 systems are assessed. However, this requirement to look at multiple dimensions in order to asses C2 does not obviate the value of performing integrated analyses of human factors and organisational issues.

2.5 CONCLUSIONS

(1) C2 analyses must consider human factors and organisational issues.

(2) Human performance issues (such as fatigue) should be incorporated as parameters in models used to analyse issues that require human activity.

(3) Decision making that is rule or algorithmically based can be modelled directly, but error rates should be estimated if humans are involved in the relevant decision making.

(4) Consequently, decisions are programmable (with appropriate error rates) but also require estimations of when decision would be made.

(5) Complex decisions are currently best treated with "human in the loop" tools and techniques, but new techniques are being developed (see Chapter 5).

(6) Both quality of decisions and command style should be considered in C2 analyses that focus on specific decision making.

(7) Organisational issues can be decomposed into constituent elements for analysis.

(8) Hypotheses or propositional structures are often the most useful approach to human factors and organisational issues.

(9) 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.

(10) 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.

2.6 RECOMMENDATIONS

(1) Human factors and organisational issues should be reviewed early in the process of C2 analysis and incorporated into later steps such as scenario development, tool selection and data analysis.

(2) Human factors and organisational expertise should be included on all C2 analysis teams, at least until a decision can be made that they are not major elements of the analysis.

(3) Separate human performance issues (such as fatigue) from cognitive issues (decision making) when possible, but recognise that they interact.

(4) Use a checklist and hypothesis testing logic for reviewing organisational issues, with explicit consideration of structural, functional, and capacity arenas. Remember that these three arenas can also interact.

(5) Integrated analytic tools that focus on key variables that drive human factors and organisational issues will often prove useful in simplifying their analysis.

(6) Sensitivity analyses are particularly important when working with human factors and organisational issues.

2.7 REFERENCES FOR FURTHER INFORMATION

141. This chapter is based in part on the results of the SAS-002 workshop on C3I systems, structures, organisations and staff performance evaluations. Additional references include:

(1) Alberts, D. & Hayes, R.E., *Command Arrangements for Peace Operations*, National Defense University, Washington, DC, May 1995.

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(3) Deutsch, R. & Hayes, R.E., *Personality and Social Interaction of Effective Expert Analysts: The Issue of Cognitive Complexity* Technical Paper, April 1990.

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(5) Dodd, L., Adaptive C2 Modelling for RISTA Effectiveness Studies. *Second International Command & Control Research & Technology Symposium Proceedings*, National Defense University, Washington, DC, 1995.

(6) Hayes, R.E., *Systematic Assessment of C2 Effectiveness and its Determinants*, 1994 Symposium on C2 Research and Decision Aids, Naval Post Graduate School, Monterey, CA, June 1994.

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(8) Moffat, J. & Perry, W., Measuring the Effects of Knowledge in Military Campaigns. *Second International Command & Control Research & Technology Symposium Proceedings*, National Defense University, Washington, DC, 1996.

(9) Noble D. & Flynn W., *RPD Tool Concept Document*, Engineering Research Associates, Vienna, VA, 1993.

(10)Noble, D., Flynn, W. & Lanham, S., *The TADMUS RPD Tool: Decision Support for Threat Assessment and Response Selection*. Paper presented at the 10th Annual Conference on Command and Control Decision Aids, June 1993.

(11)Van Creveld, M., *Command in War*, Cambridge, MA: Harvard University Press, 1985.

CHAPTER 3

SCENARIOS

3.1 INTRODUCTION

3.1.1 Purpose

142. 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 OA. This chapter addresses the role of scenarios in C2 analysis. Figure 1.1 in Chapter 1 shows the role played by scenarios in the overall C2 analysis methodology.

143. The analyst crafts a scenario or scenarios to provide the context or environment for the conduct of the operational analysis. The scenario(s) bounds the arena of the analysis and is used by the analyst to focus the analysis on central issues.

3.1.2 Definitions

144. The following definitions are of particular relevance to this COBP:

145. 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.

146. Approved scenario: A scenario adopted by the political and military community.

147. Planning scenario: A scenario for planning analysis purposes, in which the scenario parameters are described in more detail:

(1) The time frame of the analysis is defined;

(2) The geographic area is defined;

(3) The meteorological environment is defined;

(4) The political, economic, and social context are defined;

(5) The mission objectives and constraints are defined;

(6) The level of threat is defined;

(7) Friendly forces are defined;

(8) Adversary forces (e.g., enemy order of battle) are defined; and

(9) Non-combatant and other relevant actors are defined;

148. Operational scenario: A scenario for combat analysis purposes, for which additional details are added to the planning scenario elements, especially with respect to threats, orders of battle, tactics, rules of engagement, courses of action, deployment, and reserves.

3.2 ISSUES REGARDING THE USE OF SCENARIOS

3.2.1 Role Of Scenarios In C2 Analysis

149. 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 section 2.2.2). There is no single linear dimension for organisations. 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 scenario.

150. The formulation of the original problem dictates the contents of the scenario. There are no overall scenarios which are independent of a specific problem. Scenarios are not generic, but must be customised. The boundaries of the scenario space are defined in part by the issues unique to the problem under analysis.

151. Organisational issues include the involvement of various levels of hierarchy, 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 decision making process and staff activities in support of this process.

152. 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:

(1) Defence-planning;

(2) Force structures and organisation;

(3) Mission analysis;

(4) Doctrine/tactics development;

(5) Cost-benefit/effectiveness analysis;

(6) Training and education;

(7) Balancing C2 systems and weapon/sensor systems; and

(8) C2 system procurement, which will often require more detailed, task specific scenarios to cover the range of relevant system uses.

153. 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. By providing context to both the analysis and the interpretation of the results, scenarios contribute to the ultimate goal of the exercise.

3.2.1.1 Understanding and Interpreting the Results of Operational Analysis

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

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

(1) Operational benefits of C2 to be translated in the definition of MoFE;

(2) Required or desired performance thresholds and nominal MoM values; and

(3) The impact of an improved volume, accuracy and/or quality of information on the final outcome.

3.2.2 Prerequisites In Scenario Definition

156. The following prerequisites are essential before using a scenario for C2 analysis:

(1) 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.

(2) Impact: A scenario should reflect those factors that have a significant impact on C2 issues.

(3) Capability: A scenario should stress C2 capabilities, including human and organisational factors where appropriate.

(4) Credibility: Scenarios should include logical assumptions about the environment under analysis. They should represent plausible real world situations. The synthetic scenario environment should be consistent across OA studies.

(5) Utility: A scenario should be sensitive to small changes in numbers and performances.

3.3 C2 ISSUES TO BE REFLECTED IN SCENARIOS

157. This paragraph discusses those C2 elements that should be addressed or described. These items can of course also be the subject of analysis.

3.3.1 C2 Organisation and Infrastructure

158. Organisation and infrastructure 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.

3.3.2 C2 Processes

159. The scenario needs to provide for the realistic execution of the C2 processes. These include the span of control of the various command levels, 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 described in detail nor a subject of the study. These factors need to be explicitly built into the scenario(s).

3.3.3 C2 Systems

160. 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, etc.

3.3.4 Human Factors

161. 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 scenario.

3.3.5 Miscellaneous

162. 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.

163. These issues are mentioned to illustrate that in the scenario definition much attention is required to ensure that the scenario enables the proper C2 issue to be addressed in problem definition. The elements described in 3.3.1-5 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. In the scenario, the relationships between these issues should be recognised and taken into account.

3.4 APPROACH

164. In the next section, a framework for the definition of a scenario is described. Then, based on this framework, some specific aspects of actually using scenarios for C2 analysis are addressed in Chapter 5.

3.5 SCENARIO FRAMEWORK

3.5.1 Scenario Structure

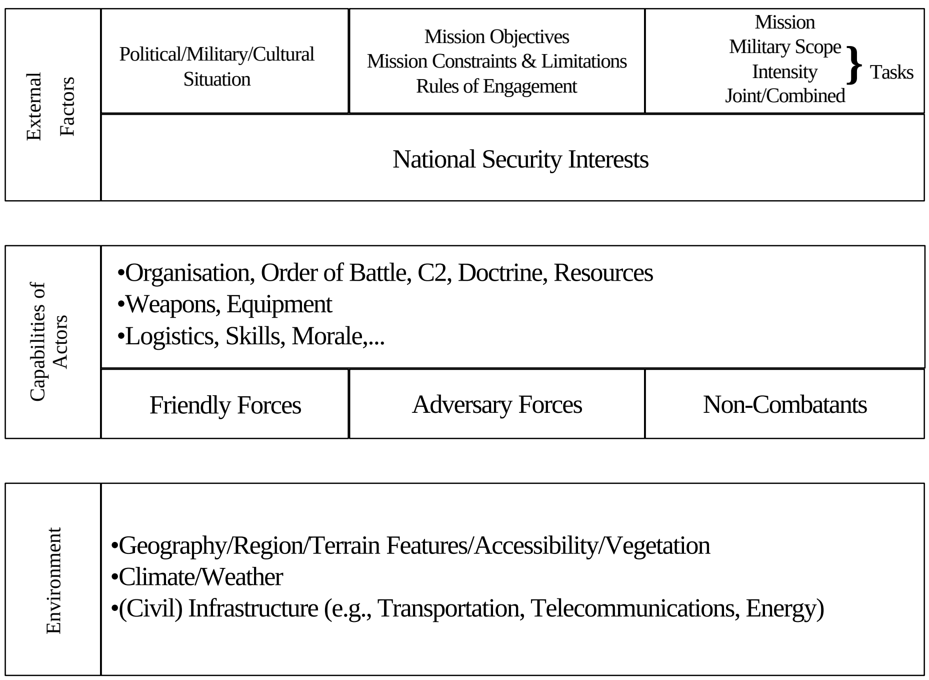
165. The general scenario framework developed from the NATO Panel 7 Ad Hoc Working Group has been adopted. See Figure 3.1.

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

167. 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. It is essential that the mission environment be addressed.

168. The intermediate level is the most challenging one. The actual military problem has to be projected on the mission, the military forces and capabilities, and the resources available.

Figure 3.1 - The Scenario Framework



3.5.2 Spectrum Of Conflict

169. Most military C2 systems are required to perform over the full spectrum of conflict from OOTW to full scale military operations. The analyst must understand when a limited scenario will enable a valid analysis and when the scenario(s) need to cover a larger portion of the spectrum of conflict.

3.5.3 Scenario Components

170. A scenario should address at least the following components:

(1) Geopolitical Situation;

(2) Geographical Area;

(a) Availability/usability of civil infrastructure;

(b) Terrain and climate.

(3) Political/Economical/Military Objectives;

(a) Level of violence, type of warfare areas, and preparation times.

(4) Mission Context and Objectives;

(a) Mission tasks and goals;

(b) National contributions, force equipment;

(c) Order of battle; and

(d) Doctrines, procedures, (range of acceptable) rules of engagement

(5) Opposition/Threat/Risks;

(a) Adversary forces;

(b) Organisation;

(c) Non combatant (refugees, IOs, etc.)

(d) C2 structures; and

(e) Assumptions/hypotheses/axioms about level of technology, impact on information defence, etc.

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

(1) Force organisation, C2 structure, force components;

(2) Doctrines, tactics, rules of engagements;

(3) Courses of action;

(4) Information systems;

(5) Concurrency; and

(6) Logistics.

172. The scenario is 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.

3.6 USING SCENARIOS FOR C2 ANALYSIS

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

(1) 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 warfare arenas connected to it (from logistics to manoeuvre, from artillery support to close combat). Therefore, the typical mission scope for C2 analysis will be broad.

(2) 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.

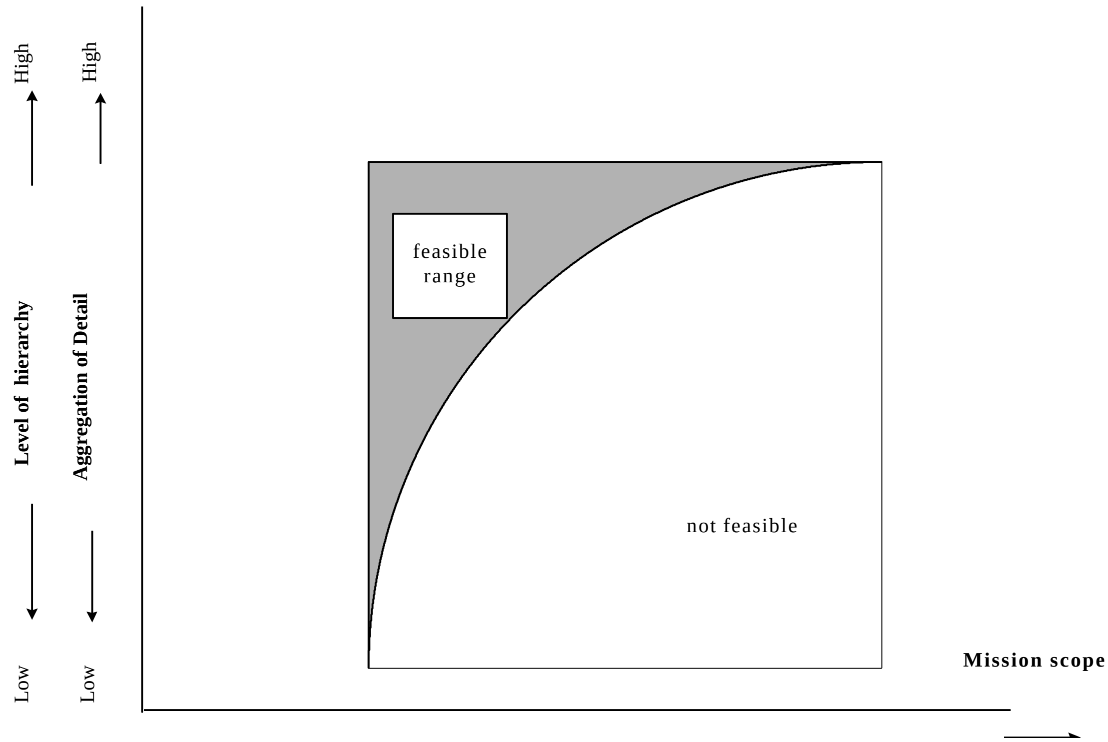
(3) Aggregation/dis-aggregation. Aggregation of data flows, data fusion in support of intelligence processes, merging C2 items to more abstract levels, etc.

turns out to be difficult, but manageable. The process of deleting, merging and combining information is reasonably well understood. The integration of soft factors 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.

3.6.1 Mission Scope Versus Levels of Hierarchy

174. 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 3.2, 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; that is, match the echelon levels to the proper aggregation level and mission scope.

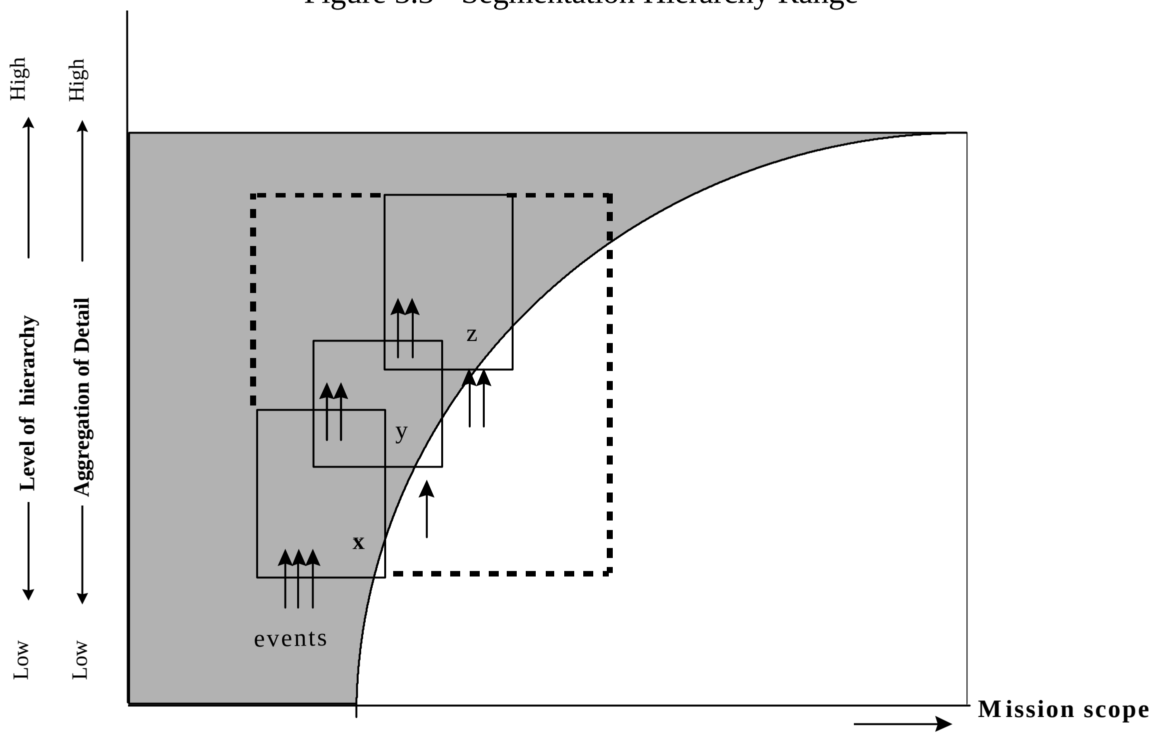
Figure 3.2 - Analysis Capabilities



3.6.2 Intersections In Hierarchy

175. In many complex problems, the analyst is required to subdivide the problem into smaller parts, perhaps even using different models for 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 3.3 graphically depicts this relationship, with the rectangles X, Y, and Z representing different models.

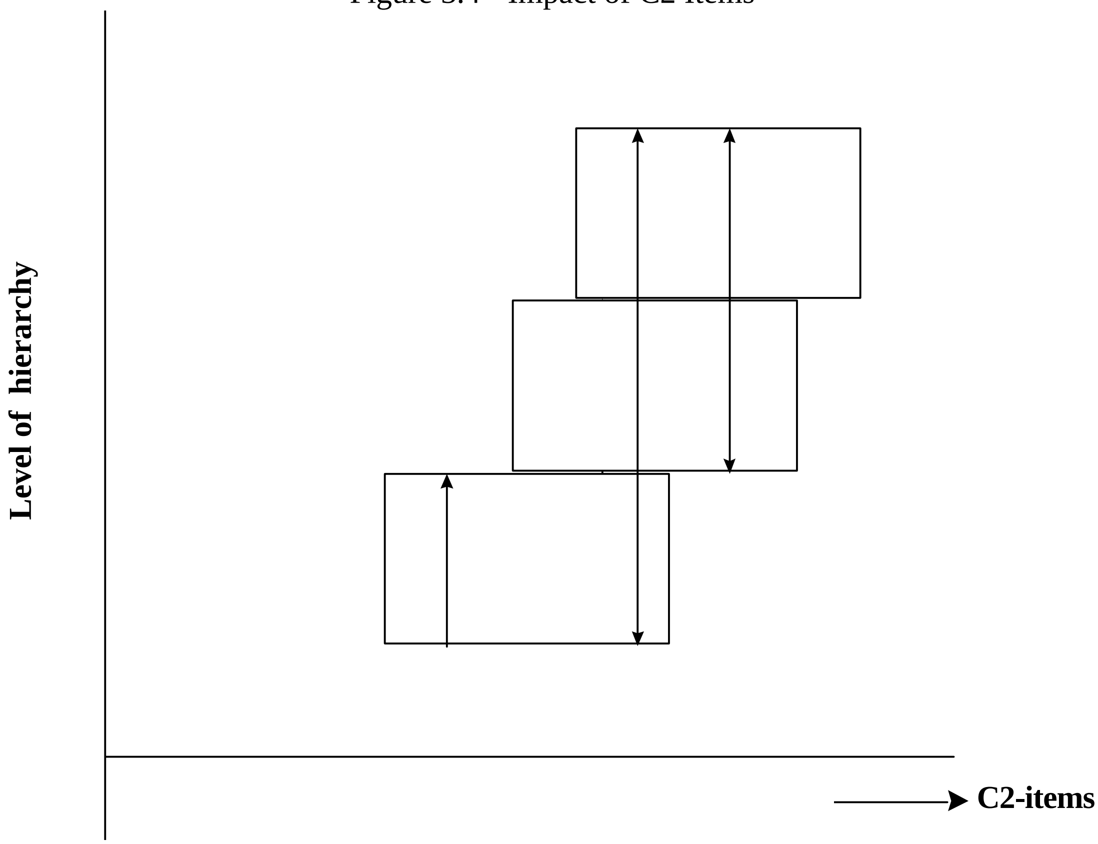
Figure 3.3 - Segmentation Hierarchy Range



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

176. 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. As illustrated in figure 3.4, 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. In Figure 3.4, each rectangle represents a model and the arrows reflect the impact of C2 items on the various hierarchical levels. 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.

Figure 3.4 - Impact of C2 Items



3.6.4 Additional Aspects

177. Additional areas of consideration:

(1) Specification: The purpose of the C2 analysis will influence the kind of scenarios to be used. There are no generic scenarios for C2 analysis.

(2) Merging mission warfare areas: Mission areas for the various levels of conflict are not discrete, and it may be necessary to include elements of more than one type into a scenario.

(3) 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 warfare areas.

(4) 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.

(5) Assumptions and Guidelines: The scenario is part of the process in developing an analysis (See Figure 1.1). 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.

(6) 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 VV&A information on the scenario(s).

(7) Awareness: Create awareness of the robustness of the overall conclusions and decisions; be aware of the degrees of uncertainty in the scenario.

3.7 CONCLUSIONS

(1) 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.

(2) Five prerequisites should be in place before using a scenario for C2 analysis:

(a) It should be approved;

(b) It should reflect the factors that have significant impact on C2 needs;

(c) It should stress C2 issues;

(d) It should be military credible; and

(e) It should enable the design and contribute to the design process.

(3) At least the following three C2 elements should be reflected in a scenario in order to make it useful for C2 analysis:

(a) The C2 organisation and infrastructure, including human factors;

(b) The C2 processes; and

(c) The C2 systems.

(4) Scenario guiding directives should indicate how the scenario has been used in a hierarchy of scenarios (interpretation of input and output events, etc.).

(5) The actual C2 analysis problem usually will be broader in scope than OA will allow. Hence Scenario Analysis in combination with military judgement must bridge this gap.

(6) Analysts need to use multiple scenarios; no single scenario is sufficient.

3.8 RECOMMENDATIONS

3.8.1 Practice

(1) Create a (national) base of approved scenarios, reflecting the military objectives within the national hierarchy of operations and thus the required spectrum of military missions and capabilities.

(2) 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.

(3) Information and hypotheses on threats, adversary forces, and non-combatants should be addressed in the scenario.

(4) Explicitly identify the C2 aspects under consideration within the problem definition.

(5) During the analysis, the key scenario assumptions should be identified and documented.

3.8.2 Challenges

(1) Standards for judging the applicability, and accreditation of (existing) models should be developed, and include consideration of a proper scenario definition.

(2) The joint use of scenarios to include possible coalitions might be established, by means of internetting computers.

3.9 REFERENCES FOR FURTHER INFORMATION

178. This chapter is based in part on the results of the SAS-002 workshop on scenario development.

CHAPTER 4

MEASURES OF MERIT

4.1 INTRODUCTION

179. This section outlines the best practices in the definition and application of measures of merit (MoM) for C2 systems. In order to understand the impact of C2 on the battlefield, it is necessary to not only analyse and measure the effect of C2 on military operations, but also the effect of the components of the constituent systems. No single measure or methodology exists that satisfactorily assesses the overall effectiveness of C2 systems. Therefore, a multi-faceted, multi-phase approach is necessary. The benefits of systems should be evaluated through their impact on the fulfilment of the military objectives within the scenarios and their impact should be measured in terms of defined qualities which are relevant to the objectives.

180. During the last two decades, many new automated C2 systems have been developed and fielded. However, the determination of the effectiveness of these systems has proven to be a complex problem. Recognising this, the US Military Operations Research Society has sponsored several workshops on MoM since 1985. The workshops have lead to the development of an analysis framework (MCES - Modular Command and Control Evaluation Structure) for the measurement of performance and effectiveness within a conceptual model for C2. Based on the Military Operations Research Society (MORS) workshops, the TRADOC Analysis Centre (TRAC) developed the C2 Measures of Effectiveness Handbook in 1990. These documents and the measurement tools developed for the Headquarters Effectiveness Assessment System (HEAT), [4.1] and the Army Command and Control Evaluation System (ACCES) represent the established best practices.

4.1.1 Approach to This Chapter

181. The AC/243 Panel 7 Ad Hoc Working Group (AHWG) on the Impact of C3I on the Battlefield [4.2] 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."

4.1.2 Definitions

182. It has been recognised that a single definition for measures of effectiveness and performance 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.

183. 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.

(1) Measures of Force Effectiveness (MoFE) which focus on how a force performs its mission or the degree to which it meets its objectives.

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

(3) Measures of Performance (MoP) which focus on internal system structure, characteristics and behaviour. Performance measures of a system may be reduced to measures based on time, accuracy, capacity or a combination that may be interdependent.

(4) Dimensional Parameters which are the properties or characteristics inherent in the physical C2 systems.

184. This hierarchical definition allows the linking of low level measures to higher levels. The lower level measures may be analysed to provide an indication of the impact on higher level measures. However, this impact is often difficult, if not impossible, to assess in detail because of the need to control for variables outside the scope of the C2 system. However, the best practice is to seek and assess linkages across these boundaries while being clear about the residual uncertainty in the analysis. See also Paragraph 42 and Figure 1.4 - Relationships Among Classes of Measures of Merit.

4.2 ISSUES

4.2.1 Objectives

185. The important issues raised by decision makers are how to arrive at judgements of the degree to which C2 performance may improve force effectiveness, and subsequently provide convincing demonstrations of those improvements. The ideal approach may be to define a single measure which reflects the military and political objectives of the missions under consideration. Determination of such a measure is generally not feasible, although not necessarily impossible for particular classes. In most practical decision making problems, it is necessary to define several measures to approach the ideal. Furthermore, a single measure may not provide sufficient scope and/or detail to analyse the impact of specific C2 elements.

186. An important step in the design of an evaluation is the establishment of the objective(s) of the evaluation. MoM have different purposes, but in all cases they are used to compare different options on equal terms. MoM typically serve a wide range of purposes, including:

(1) For new requirements, the establishment of a standard or expectation of performance;

(2) The establishment of the bounds of performance of a system as well as the effects of imposed constraints;

(3) The comparison and selection of alternative systems that may be very dissimilar but are designed to achieve a similar purpose;

(4) The assessment of the utilisation of a system in new or unexpected application domains or missions;

(5) The identification of potential weaknesses in specific areas of an organisation or system (areas of high error potential or high user workload);

(6) Analysis of the impacts of organisational changes;

(7) Analysis of training effectiveness;

(8) The determination of the most cost-effective approaches to achieve desired objectives;

(9) The comparison of a replacement system, or components of a system, against predecessors or competitors;

(10) Assistance in requirements generation and validation and the derivation of specific C2 requirements from broad statements of objectives; and

(11) The evaluation of the effectiveness of human decision making in the C2 cycle.

4.2.2 Characteristics

187. The relationships between types of measures are often difficult to establish authoritatively. Linkages between lower-level measures (DP and MoP) are relatively easier to determine than those between higher-level measures (MoE and MoFE), particularly when only a small number of observations are available, making correlation techniques inappropriate, and/or controls are not available to isolate causal effects. MoE and MoFE are more dependent on the operational context and are therefore more scenario dependent. This implies the necessity for a selected range of scenarios for the proper analysis and interpretation of the measures. MoFE tend to be few in number and difficult to obtain. However, they should, whenever practical, be used in context with MoE and MoP that provide diagnostic information about the dynamics of the C2 process. Table 4.1 lists general characteristics of the types of measures.

Table 4.1 - Tendencies of Characteristics of MoM

MoM	Focus	Scenario	Effort Required	Number	Value	Compre-hension	Generalis-ability
MoFE	Outcome	Dependent	High	Few	High	Military	Low
MoE	C3I	↕	↕	↕	↕	↕	↕
MoP	Systems						
DP	Process	Independent	Low	Many	Limited	Technical	High

4.2.3 Properties

188. 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 (artillery vs. infantry), rank or ordinal (e.g., worst to best), relative or interval value (e.g., 10% increase), absolute value or ratio (e.g., 2 kilobits per second).

189. The key properties for quality assurance are reliability and validity. Other significant properties include effort required and convenience of measurement. Measurements should be easy to capture and easy to apply. The effort required for collection bears no direct relationship with validity, but reliability may be related to cost. Reliable measurements require repeated observations and large sample sizes. A cost-effective measurement plan provides enough data for useful and definitive conclusions. However, cost of measurement may be an overriding factor in system evaluation.

190. 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 validly link 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.

191. MCES lists several other quality criteria for measures, which may be grouped according to properties related to reliability and validity as discussed below.

4.2.3.1 Validity

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

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

(2) Construct (also referred to as content) validity means that the target object, and only the object, is measured.

(3) 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.

(4) External validity is the extent to which results may be extended to other populations or environments. Associated with this is expert validity, which refers to the degree to which a measures are accepted by those knowledgeable in the field.

193. A Measure of Merit should attempt to meet the following criteria:

Table 4.2 - MCES Validity Criteria of Measures

Validity Criteria	Definition
Is it Mission Oriented?	Relates to force/system mission
Is it Realistic?	Relates realistically to the C2 system and associated uncertainties
Is it Appropriate?	Relates to acceptable standards and analysis objectives
Is it Inclusive?	Reflects those standards required by the analysis objectives
Is it Simple?	Easily understood by users

4.2.3.2 Reliability

194. 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 amount of error (measures of dispersion such as variance or standard deviation) associated with measurement must be known to interpret results and to discriminate between real effects and statistical effects.

195. A measure of merit should attempt to meet the following reliability criteria:

Table 4.3 - MCES Reliability Criteria of Measures

Reliability Criteria	Definition
Is it Discriminatory?	Identifies real differences between alternatives
Is it Measurable?	Able to be computed or estimated
Is it Quantitative?	Can be assigned numbers or ranks
Is it Objective?	Defined or derived, independent of subjective opinion
Is it Sensitive?	Reflects changes in system variables

.

4.3 APPROACH TO THE EVALUATION FRAMEWORK

196. The evaluation of C2 systems requires the application of a framework to yield appropriate MoM. Analyses of C2 systems 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.

197. If the analyst assumes that C2 effectiveness is synonymous 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. These are measures of C2 effectiveness.

198. An evaluation framework encompasses several factors as discussed in the introductory chapter. Typical factors include:

(1) The evaluation configuration - e.g., storyboard, testbed, constructive simulation, field trial;

(2) The evaluation goal or purpose;

(3) The context, assumptions, and constraints;

(4) The evaluation measures - MoFE, MoE, MoP, DP;

(5) The identification of specific measures;

(6) The scenario or stimulus;

(7) The collection means - e.g., subject matter experts, automatic data logging;

(8) The specification of the measures; and

(9) The interpretation of results.

4.3.1 Types of Measures

199. A common thread in the approaches for C2 evaluation 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.

200. 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 of the critical elements for successful task completion.

201. 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.

4.3.1.1 Time

202. For C2 tasks, time based metrics include:

(1) The time taken to react to an event (time to notice process, and act upon new information;

(2) The time to perform a task (time to make decision);

(3) The time into the future for predictive analysis; and

(4) The rate of performing tasks (tempo).

4.3.1.2 Accuracy

203. Metrics for accuracy include:

(1) Precision of performance;

(2) Reliability of performance;

(3) Completeness (known unknowns, unknown unknowns);

(4) Errors (alpha, beta, omission, transposition, severity); and

(5) Quality of information produced.

204. Some accuracy measures may be measured in units of time; for example, 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 data.

4.3.2 Relationships - Time and Accuracy

205. 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.

206. Table 4.4 contains examples of time and accuracy based measures. These measures are measures of effectiveness.

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 decision making	Quality of tactical plan

4.3.3 Examples of Measures of Performance

207. Table 4.5 [4.12] provides examples of measures of performance.

Table 4.5 - Examples of Measures of Performance

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
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
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
User Effectiveness - Time Related	
Response time	Response to requests within established times
Timeliness	Information available at appropriate time
Ease of use	Ease of access to information
Training time	Time to train users
Decision response time	Time available to commanders

4.3.4 Headquarters C2 Measures

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

(1) Monitoring and understanding: information transmission, values, times, effect, comprehension;

(2) Planning: information exchange, co-ordination, impact, flexibility, process quality; and

(3) Directing and disseminating.

209. 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.

4.4 SOME EXAMPLES OF EXPERIENCE

4.4.1 MCES

210. 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.

211. 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 leaves the details of the measurement, data collection, and analysis plans to the analyst.

212. MCES considers C2 as consisting of three components: physical entities (equipment, software, people), structure (interrelationships of entities), and processes (C2 functions), with the boundary of a C2 system being defined as a delineation between the system studied and the environment. The TRADOC C2 MoE Handbook adds mission objective as the top layer of the hierarchy of C2 components.

213. MCES focuses on measures as opposed to models, but includes the cybernetic loop model of generic C2. It consists of seven procedural steps. The MCES process is described in more detail in Annex VII.

4.4.2 ACCES - Army Command and Control Evaluation System

214. 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, and 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 for generation of plans which 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. Details are given in Annex VII.

4.4.3 MAUT

215. MAUT, or Multi-Attribute Utility Theory, 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 and the MAUT assigns a utility component for each element and node in the hierarchy. 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. If properly applied, this approach will allow integrated assessment across multiple dimensions of assessment. While this is often satisfying to decision makers (it provides a single index of quality), analysis should always monitor the components of such indices and they may provide insight into strength and weaknesses of the C2 system. MAUT results should always be assessed by sensitivity analyses. Details are given in Annex VII.

4.5 OTHER CONSIDERATIONS IN THE SELECTION AND INTERPRETATION OF MOM

4.5.1 Effects of Uncertainty

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

(1) Study Assumptions: Uncertainties in the scenario (model input); e.g., 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.

(2) Modelling Assumptions: Uncertainties in the model (structural uncertainty); e.g., 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.

(3) 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), decision making for local versus global optimisations, etc.

217. Sensitivity analysis may be applied to reduce uncertainty. By varying the assumptions and input data within the plausible ranges, excursions in the analysis provide insight into the effects of uncertainty.

218. It should be noted that uncertainties in the scenario often reflect real-world situations where a range of diverse, often anticipated, conditions may be encountered. Measures appropriate to those diverse conditions are *flexibility* and *robustness*: flexibility for different anticipated situations, and robustness for the unanticipated conditions [4.13].

4.5.2 OOTW

219. While national NATO policies require that military forces be prepared for high intensity conflict, forces have been increasingly involved in low-intensity conflicts and OOTW. 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, organised crime, civil unrest, migration, or other territorial intrusions. Most OOTW are characterised by their joint or combined nature. While not a principal focus for the Code of Best Practice, OOTW are missions where C2 analyses are becoming important. Some insights into their additional complexity can be offered.

220. While the determination of MoM has been stated as difficult to obtain, OOTW offers even more of a challenge. Traditional MoE and MoFE such as loss exchange ratios, combat effectiveness, or duration of the campaign are not always applicable to OOTW. In such operations, military forces may play important roles but political concerns may limit the scope of imposition of 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.

221. 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 a deterrence or coercion on the parties in conflict.

222. Normality Indicators [Ref. 4.13] have been proposed as an indirect method for measuring the effects of military involvement in OOTW, although causal relationships are difficult to prove. These measures may be obtained by evaluating the extent to which conditions have been restored to previous levels.

223. Ref. 4.13 developed low-level measures to cover OOTW. These include, for example:

(1) The time between the arrival of friendly forces in the area and the deployment of the forces;

(2) The time between deployment of friendly forces and contact with adversary forces;

(3) The length of time adversary forces were under observation without posing a threat to friendly forces, and;

(4) The length of time friendly forces are in potential danger (i.e. adversary forces have the opportunity to fire on friendly forces).

224. Ref. 4.13 identified a structure that provides high-level measures. Some examples are:

(1) Opportunities to employ forces, which reflects the range of military capabilities available;

(2) Strategic Deployment, related to deploying and recovering the right force to theatre efficiently and in time;

(3) Endurance, to maintain an effective force in theatre for an extended time;

(4) Mission objectives, to measure the success of achieving military objectives in OOTW; and

(5) Successful termination, to deal with progress to the desired end state (the criteria may be political and not yield measures related to military activities).

4.5.3 Measures of Policy Effectiveness

225. 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. A new category of measure may be added to characterise the contribution of military actions to broader policy societal outcomes, Measures of Policy Effectiveness (MoPE). Military missions may not directly achieve policy objectives, they may provide an environment more conducive to these objectives. However, measures of effectiveness of military tasks should quantify performance against military missions, not the overall political aspirations.

4.5.4 Information Operations

226. IO may be considered as information dominance over opposing forces and its military application (from pre- to post-hostilities) in terms of C2 warfare. The aims are to influence, degrade, or destroy adversary C2 capabilities and information links, while using countermeasures to protect one’s own C2 assets. IO is a form of comprehensive warfare which may span peacetime, crisis, and combat, governed by a strategy to obtain desired objectives which may be military, political, or economic. The ultimate objective is to affect the adversary’s decision process, implying a hierarchical effect on opposing forces operations with, for example, attacks on sensors affecting information systems, to the propagation of functional effects on decision making. For MoM, hierarchical levels similar to the MORS

levels may be appropriate, but the MoM would be difficult to evaluate and become quite subjective at the higher levels.

4.6 IMPACT OF TECHNOLOGICAL CHANGES

227. The rapid pace of technology changes involving information systems is causing several major changes in C2 as perceived and executed, leading to potential changes in the way war fighting commands are organised. To keep pace and to evaluate the impacts and/or benefits of these changes, the nature of these changes and benefits need to be understood so that the appropriate MoM can be developed.

228. 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. Details are provided in Annex VII.

4.7 CONCLUSIONS

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

(1) Determine the levels of hierarchy appropriate for the level of analysis to establish appropriate MoM;

(2) Identify specific MoM which are practically obtainable;

(3) Specify means of collection of MoM;

(4) Assure the validity and reliability of measures for correct interpretation with quantifiable levels of confidence;

(5) 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;

(6) Consider that while MoFE may provide the most persuasive measures from the military perspective, MoE and MoP are the most meaningful from the OA analyst viewpoint; and

(7) Account for the principles of reliability and validity to avoid the risk of generating false conclusions.

4.8 RECOMMENDATIONS FOR GENERATION AND SELECTION OF MOM

230. The principal objective for MoM is to determine judgements of the degree to which C2 acquisitions 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 its effectiveness on military missions, and not on 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:

(1) The objectives for the evaluation must be established and clearly stated.

(2) The assumptions used in the model and/or evaluation must be stated along with their potential impact on the results. Likewise for any constraints placed on either the evaluation process or the system(s) being assessed .

(3) 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.

(4) 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.

4.9 CHALLENGES/ISSUES FOR THE EVALUATION OF C2 SYSTEMS

(1) Correlation of force effectiveness measures with C2 process measures (e.g. battle outcome against lower level measures) is difficult at best.

(2) Separation and linkage of C2 & users / C2 & organisation / C2 & military objective requires some effort.

(3) Summary measures (e.g. ACCES) 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.

(4) 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.

(5) The analyst must pay attention to the complex task of the establishment and measurement of control variables in order to achieve correlation of measures against a wide spectrum of scenarios and staff.

(6) The definition of criteria to differentiate measures must be established.

(7) The verification of measurement criteria (e.g. discrimination) must be ensured.

(8) For the near future, at least, collection of data to support C2 measures will remain labour intensive because C2 processes remain human intensive.

(9) Many of the measures for information processing concern completeness of the information. Deciding what makes information complete requires co-ordination and co-operation between the assessor and the user.

(10) The relationship between outcome and process may be complex because C2 is an integrated system with continuous feedback.

(11) The analysis of uncertainties, (C2 decisions are made in situations with degrees of uncertainty, therefore the outcome is no more important than the evaluation of the quality of process) remains important. Measures of central tendency and dispersion are both significant when examining C2 issues.

(12) A Command Post Exercise (CPX) is the preferred venue for evaluation of C2. However, the costs involved generally preclude conducting a CPX solely to evaluate the C2 process or a C2 system.

4.10 REFERENCES FOR FURTHER INFORMATION

231. This chapter is based on the results of the SAS-002 workshop on Measures of Merit. Additional references include:

(1) Defense Systems Inc. (1982), Theatre Headquarters Effectiveness: Its Measurement And Relationship To Size, Structure, Functions, And Linkages; Vol 1: Measures Of Effectiveness And The Headquarters Effectiveness Assessment Tool, Defense Systems Inc., McLean, VA.

(2) NATO Technical Report AC243 (Panel-7) TR/4, Ad Hoc Working Group on the Impact of C3I on the Battlefield.

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CHAPTER 5

TOOLS (MODELS) AND THEIR APPLICATION

5.1 INTRODUCTION

5.1.1 Purpose

232. The purpose of this chapter of the COBP is to consider the best methods for representing C2 systems, processes and organisations in models. In consonance with the aims of SAS-002, the focus is on the land environment, and the key objective of such models is to establish an ‘audit trail’ from individual sensors systems, communication systems or other C2 systems, concepts, or organisations, all the way through to high level measures of their effects on battle outcome, such as time to achieve military objectives, or likely casualty levels.

5.1.2 Definition

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

5.1.3 Background

234. To address the challenges with modelling C2, a workshop on modelling C2 was held 7-8 July 1997 in conjunction with the fifth meeting of the NATO Panel 7 Research Study Group-19 (RSG-19) on C3I Modelling that took place 7-10 July 1997 in The Hague, Netherlands. (See Annex V, Summary of Workshop Minutes.) The goals of the workshop were to identify the general status of current and future modelling of C2 across member nations, to summarise current C2 modelling approaches, to identify promising C2 modelling approaches for inclusion in this COBP, and to focus the organisation/structure of the SAS-002 C3I Symposium to be conducted in January 1999.

235. In total, presentations were given by seven different participating countries, as well as the NC3A, covering sixteen different models or modelling approaches. The

presentations included the full range of models, including both performance and effectiveness models, both object oriented and procedure oriented models, and models of company through command levels above corps.

236. This chapter of the Code of Best Practice is a distillation of the best approaches and ideas being considered in current research across NATO for representing C2 in constructive simulation models of high intensity land operations. A great breadth of methodologies have been made available, through the workshop briefings. The briefings covered approaches which brought together live, virtual, and constructive simulation; including both stochastic and deterministic methods, and brought out issues such as model validation.

5.2 ISSUES

237. This section addresses the core problem of analysing the effectiveness of C2 related systems, and what it is that sets it apart from other types of Operational Analysis. The key to the problem lies in making a properly quantified linkage between C2 MoP, such as communication system delays, C2 MoE such as planning time, and their resultant impact on higher level MoFE, such as friendly casualties, attrition effects, and time to achieve military objectives, which capture the emergent effects on battle outcome. These higher level MoFE 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. Hence, all analyses of C2 systems demand a high level of creative problem structuring and approach to overcome this challenge.

238. Other modelling issues that proved important to C2 analysis were:

(1) Representation of human behaviour: rule-based, algorithmic, or “Human-in-the-loop”;

(2) Homogeneous models versus hierarchies/federations;

(3) Stochastic versus deterministic models;

(4) Adversarial representation;

(5) Verification, Validation, and Accreditation (VV&A); and,

(6) The conduct of sensitivity analysis.

5.3 STEPS IN DEVELOPING THE COBP FOR MODELS

239. This section expands on the results of the C3I Modelling Workshop which employed a specific approach for the identification of best practices for C2 modelling. (Annex V, page 7) This approach includes four steps:

(1) Present national approaches. Individual nations presented to the workshop the approaches for C2 modelling and analysis which they have found to be successful. A copy of individual national presentations made at the workshop can be found in the official minutes of the workshop, published separately.

(2) Select best practices. As national presentations were made, the workshop members discussed the merits of each approach and whether it warranted inclusion in the COBP.

(3) Develop a general set of C2 modelling requirements. The workshop accepted a set of general C2 modelling requirements. These requirements are discussed in paragraph 5.5.3 below.

(4) Assess current strengths and weaknesses. The workshop participants compared the C2 modelling requirements to the current approaches presented by member nations to identify strengths and weaknesses in current C2 modelling capabilities. Identified strengths are discussed in section 5.7.1 below. Also identified by the workshop were resultant areas which exist as remaining challenges. These challenges are discussed in section 5.7.2 below.

5.4 EXPERIENCE

5.4.1 Representation of Human Behaviour: Rule-Based, Algorithmic, or “Human-in-the Loop”

240. In developing models which represent the process of C2, most approaches until very recently have been founded on the artificial intelligence (AI) methods of expert systems. These represent the commander’s decision-making 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 models which are large, complex, and slow running. The decision rules themselves are, in many cases, very scenario dependent and,

as noted in Chapter 2, human factors and organisational expertise may be needed on a project team to treat these issues correctly.

241. 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 models, which can easily represent a wide range of scenarios, yet still have a representation of C2 which is 'good enough.' Some authors have begun to explore advanced algorithmic tools based on mathematics such as catastrophe theory and complexity theory. This is discussed below under new methods.

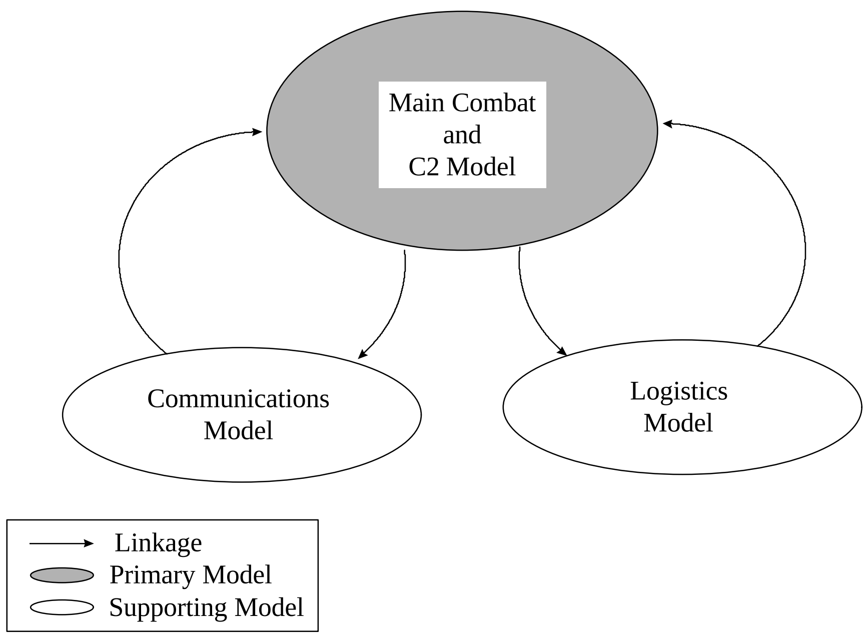
242. Many analyses employ "human in the loop" techniques in order to ensure realistic human performance or to check assumptions and parameters. However, "human in the loop" techniques are expensive and require the inclusion of soft factors and their attendant MoM. The introduction of human factors also raises the level of uncertainty as these factors are difficult to integrate and are not necessarily well understood in the C2 specific context. The increased cost, complexity, and uncertainty of "human in the loop" requires analysts to use these techniques for small portions of the overall problem structure, rather than as the primary analytical method.

5.4.2 Homogeneous Models Versus Hierarchies/Federations

243. In order to establish the audit trail referred to earlier, tying individual C2 systems, processes, and organisations to battle outcomes, there is a need to represent all the detailed processes involved, such as the transmission of communications across the battlefield and the impact of logistics on decision making. 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 in the main model explicitly, or whether this aspect should be split out as a supporting model of the overall process. Similarly, the detailed logistics modelling required to establish constraints on decision making could be undertaken as part of the main model or in a specialised supporting model. These 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 rerun. 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. The high rate of services that may be required to support the main model can involve a long analysis process. This method becomes critical with a large assortment of C2 parameters or a long scenario period. Sensitivity analysis requirement may also contribute to the requirements for implementation of this approach.

Figure 5.1 - Illustrative Model Linkage



244. Figure 5.1 shows the main model 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 models of the communications and logistics infrastructure. Those supporting models can then match 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 are adjusted iteratively to bring the two models into balance. This approach is more flexible and reactive for a large set of C2 assessments. Nevertheless, the main

disadvantage arises from the complexity of the architecture itself (number of linked sub-processes, failure of the sub-model, etc.).

245. 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 demand they place on the supporting infrastructures. Then, as before, 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 leads to 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.

5.4.3 Stochastic Versus Deterministic Models

246. The ideas of chaos theory show 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 up to 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 a 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.

5.4.4 Representing Adversary Forces

247. 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 between friendly and adversary forces is a critical element of C2 representation. Today, much more robust adversary capabilities 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.

5.4.5 Verification, Validation, and Accreditation (VV&A)

248. VV&A has traditionally 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 which involve the human aspects of information processing and decision making.

5.5 NEW METHODS

5.5.1 Emerging Best Practice - The Model Level

249. The potential for exploiting recent advances in mathematics in order to create fast running models was noted earlier. Such models will need to exploit emerging approaches, such as complexity theory, chaos theory, catastrophe theory, and game theory, if they hope to produce such a ‘good enough’ representation. They will probably often 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.

5.5.1.1 Model Federations

250. A number of new approaches share a key set of characteristics. An object-oriented approach within the model 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 models 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 models 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 models, to fully address the study issues.

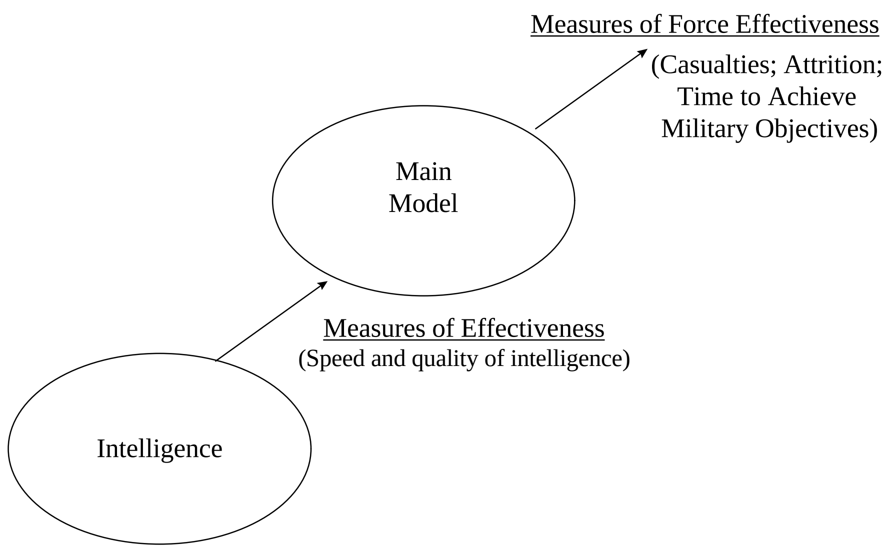
5.5.1.2 Agent-Oriented Modelling

251. 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.

5.5.1.3 Linking of Performance Models to Effectiveness Models

252. This third idea, used in a number of NATO countries, uses a structured hierarchy of models to create an audit trail from C2 systems, processes, and organisations through to battle outcome. The idea is to create supporting performance level models 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 in Section 5.4.2.

Figure 5.2 - Model Hierarchy



253. For example, a detailed model of the intelligence system can be very complex, if we wish to take account flow of intelligence requirements, taskings, 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 which captures all of this detail can be created (or used if one already exists) in order to produce outputs at the MoE level, such as speed and quality of intelligence. These can then form inputs to the main simulation model. The main model 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.

5.5.1.4 Scanning Scenario Space

254. The use of very fast models 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 must represent in order to conduct the desired level of analysis.

5.5.1.5 Decision Making Process

255. It was accepted that it is important to have a proper representation of the decision-making process, in order to establish the link from C2 performance through measures of effectiveness to overall force effectiveness, and to represent 'IO' effects such as Counter C2 or Digitisation of the Battlespace. Representation of the decision making process itself, however, remains a very difficult thing to do because of the difficulty in representing human performance, command styles and organisational relationships (See Chapter 2).

5.5.1.6 Parameter Development Context

256. Finally, it may become necessary to generate new or additional data to validate new or existing models 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 is used as part of an iterative process to develop systematically more in depth and sophisticated models or in some cases, more simplistic models to increase their validity. The original model is tested, modified, and tested 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 models exist. Each approach requires additional time and resources and the data sets may not be validated for some time.

5.5.2 Emerging Best Practice - The Algorithm Level

257. A number of common ideas emerged which are worth consideration for new model developments.

(1) 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.

(2) Representing headquarters explicitly in the model allows proper representation of Information Warfare effects such as counter C2.

(3) Explicit representation of the "Recognised Picture" within each HQ allows the model 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.

5.5.2.1 Reasoning About Missions

258. In several approaches, the key variable is the mission of the unit. Reasoning about the way in which these missions should change, as the situation develops, appears to be a sound approach to representing C2 at the levels of command below division level, for models aimed at examining force structure and policy issues.

5.5.3 C2 Modelling Guidelines

259. As discussed previously, the C2 modelling workshop identified a general set of C2 modelling guidelines based on a set of requirements presented to the Research Study Group. The primary objective of these guidelines is to relate C2 processes and systems to battle outcome. In order to do this, a model must be capable of explicitly representing the collection, processing, dissemination, and display of information. These capabilities, therefore, lead to a set of C2 modelling guidelines described below. It should be noted that these requirements are not yet fully satisfied by any existing model.

260. These guidelines should be considered part of the model selection and development processes for a specific problem. The analyst should be conscious about an explicit or implicit implementation of the consideration points. The C2 modelling guidelines are as follows:

(1) 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 both adversary and friendly forces, 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.

(2) Represent the realistic flow of information around the battlefield. 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 on the battlefield. 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 battlefield. The model should represent the communications systems and account for these degradation factors as it represents information flow.

(3) Represent the collection of information from multiple sources and tasking of information collection assets. This guideline applies equally to adversary and friendly information. For the collection of adversary information, the model 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, is essential for effective decision making.

(4) Represent the processing of information. Information is rarely valuable in 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 can have a direct bearing on combat outcome.

(5) Represent C2 systems as entities on the battlefield. C2 systems perform information collection, processing, dissemination, and display functions. They should be explicitly represented as entities which can be targeted, degraded, and/or destroyed by either physical or non-physical means. Additionally, the model should account for continuity of operations of critical functions during periods of system failure or degradation.

(6) 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.

(7) Represent commander's decisions based on his unit's perception of the battlefield. Each unit should act based on what it perceives the situation to be, not based on

ground truth available within the model. When a unit takes action based on inaccurate perceptions, it should suffer the appropriate consequences.

(8) Represent IO for each/all combatants. With information so critical to combat outcome, the model 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.

5.6 APPLICATIONS

261. Properly designed analytic tools, notably models, have a number of applications of value. Tools offer the analyst the opportunity to test and validate theories of C2, providing more insight into causal mechanisms and variable relationships. Systematic testing allows for the general improvement of theory and can improve the integration of C2 into modelling. The systematic collection and cataloguing of data generated by analytic tools adds to the available body of analytical data and knowledge bases. By tapping into these resources, analysts can develop more representative tools and validate the results of other analysts. Sharing data among analysts may reduce the resources required to develop sufficiently sophisticated tools by reducing the degree of unnecessary repetition in the development and selection of appropriate analytical tools. Finally, the application of tools and the improvement of theory and the tools themselves, helps the analyst to better answer the charge and to identify the key uncertainties and limitations of the findings of their analysis.

5.7 CONCLUSIONS

262. The analysis conducted by SAS-002 at, and subsequent to, the C2 modelling workshop resulted in the following conclusions regarding the strengths and weaknesses of current C2 modelling approaches.

5.7.1 Strengths in Current C2 Modelling

263. An assessment of current C2 modelling approaches employed by SAS-002 members against the guidelines above show that, while they may not yet be satisfied, there are some strengths in the C2 modelling approaches currently being implemented by SAS-002 members. These strengths are as follows:

(1) 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 SAS-002, the modelling of C2 is now considered possible. Member nations now seem to have both an understanding of C2 and its importance to combat, and a common understanding of the modelling challenges which exist.

(2) 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, requirements 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 outcome. Selection of the models to apply to a particular problem should be based on evaluation of specific criteria, as discussed previously in Chapter 1.

(3) 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. Although each nation develops its models for different purposes, there exists certain commonality of approaches which serve to strengthen their collective merits. These commonalities are an outgrowth of the modelling technologies now available, but also result from shared experiences by member nations. These commonalties are summarised in Annex VIII.

(4) 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.

(5) 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.

(6) There is progress in linking and federating models. Significant progress has been made by several nations in linking performance models 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.

(7) 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 outcome. Among these factors are morale, fatigue, and training proficiency. These and other soft factors have increased importance on combat outcome as C2 modelling improves in combat models.

(8) Standards exist or are under development. 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.

(9) 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.

(10) 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.

5.7.2 Weaknesses In Current C2 Modelling

264. An assessment of current C2 modelling approaches employed by SAS-002 members against the guidelines above show that weaknesses exist in current approaches. These weaknesses, rather than being enumerated here, are expressed as challenges in paragraph 5.8 below.

5.8 RECOMMENDATIONS

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

(1) Models and simulations for smaller scale contingency operations such as OOTW. As discussed previously, the focus of model development has been on high intensity combat, even as C2 modelling enhancements have been made in recent years. Recent world events and current projections call for an emphasis on contingency operations and OOTW. C2 in these environments can be quite different and may require fresh C2 modelling approaches to link C2 to outcome in these environments. SAS-002 concluded that the C2 modelling approach here could be extended into the OOTW arena.

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

(3) 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.

(4) 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.

(5) 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 battle 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.

(6) Multiple application of C2 models 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 development resources wherever possible, leads to the challenge of developing C2 models, or at least component software modules which can be used to support analysis, training, and operational requirements.

(7) 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 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.

(8) 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 recommendation in the COBP, therefore, is equally applicable to modelling of adversary forces as it is to friendly force C2. This represents a significant challenge to many modelling efforts.

(9) 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, will 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, necessitates new data generation approaches, which will take some years to generate credible data. The tasks of VV&A and 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.

(10) Verification, Validation, and Accreditation of C2 models and the parameters that drive them. This is always 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 which involve the human aspects of information processing and decision making.

(11) Sensitivity Analysis. The challenges associated with the proper conduct of sensitivity analysis of C2 is as great, 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.

5.9 REFERENCES FOR FURTHER INFORMATION

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CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 INTRODUCTION

267. This section contains the key COBP conclusions and recommendations. It is essentially a summary of the more important conclusions and recommendations from Chapters 1 - 5.

6.2 CONCLUSIONS

268. The OA communities of NATO member nations are being increasingly asked to address C2 issues in the acquisition, operational analysis, and force structure arenas. This trend, which arises from the rapid pace of change in information technology and its impact on military affairs, will continue for the foreseeable future.

269. While complex and challenging, particularly because they involve the behaviour of humans under stress in distributed locations, meaningful analyses of C2 and C2 systems are possible.

270. The traditional tools and approaches of the OA community are essential, but they need to be enhanced, combined, and expanded to fully support successful C2 analyses. Tools need to be designed from the beginning with C2 as an integrated element. It is not sufficient to assume perfect C2 or to include it as a separate add-on module.

271. Analyses of C2 issues is best done by a team that includes expertise in C2, modelling, and OA and may require specialised team members from fields such as human performance, decision making, or organisational theory.

272. Creative approaches to VV&A and VV&C will be essential for successful C2 analyses. The most effective approach to this issue is application of multiple tools and models to cross-check results.

273. Analysts need a systematic, step-by-step process that begins with an assessment of the benefits anticipated from C2 or related (organisational, personnel, process, etc.) changes

and carries through the problem structuring, examination of human performance and organisational issues, scenario specification, measure of merit selection, tool selection and application process. See Figure 1.1 - Recommended C2 Assessment Methodology.

274. The actual C2 analysis problem usually will be broader in scope than OA will allow. Hence Scenario Analysis in combination with military judgement must bridge this gap. The OA problem definition related to a scenario should not only define the problem but also show the benefits or disadvantages of solving the problem or improving performance in order to rank possible solutions based on the MoM.

275. The tasks of incorporating human factors and organisational issues into C2 analyses are complex and will require an hypothesis testing approach in most cases.

276. No single measure or methodology exists that satisfactorily assesses the overall quality of C2. The crucial causal and analytic chain for C2 analyses is the linking of dimensional parameters to measures of system performance to measures of C2 effectiveness and measures of force effectiveness. The level of analytical rigor necessary to establish these links can be achieved through the associated processes of problem decomposition and measure of merit selection.

277. The analysis conducted by the SAS-002 at, and subsequent to, the C2 modelling workshop resulted in the following conclusions regarding the strengths and weaknesses of current C2 modelling approaches.

278. Strengths:

(1) There is a common understanding of the issues;

(2) There is application of C2 modelling to a wide range of issues, and an understanding of the criticality of C2 to proper analysis of combat outcome;

(3) There is a commonality of approaches in different nations;

(4) There is progress in linking and federating models, such as, performance models with combat effectiveness models;

(5) Standards exist or are under development; and

(6) There is application of new information technologies.

279. Weaknesses:

(1) There is a lack of emphasis of modelling and simulation for other than high-intensity combat (e.g., OOTW);

(2) There is a need for better representation of the cognitive processes;

(3) There are differences in the level of modelling of friendly and enemy forces and their interactions;

(4) There is a continuing lack of "soft factors" representation and data; and

(5) There is a need for focused efforts in VV&A and VV&C.

6.3 RECOMMENDATIONS

280. Prior to the execution of a study, scenarios should be explicitly identified and described. However, over the course of the study, it might be necessary to revisit the scenario definition. Related to an approved scenario is a (model) script. If material for the creation of script data and/or model development is not available, the script must be changed, and thus the analytical capabilities must likewise be revisited.

281. The principal objective of developing MoM is to determine judgements of the degree to which C2 acquisitions may improve force effectiveness, and to provide convincing arguments for the improvements. It is important to select MoM that assess both the contributions of C2 in terms of its effectiveness on military missions and the quality of the C2 process itself.

282. Analysts should take advantage of the strengths available in current modelling approaches, and in the new methods which are evolving. They should also be aware of the challenges which must still be resolved, and should attempt to play their part in helping to address those challenges through both study activities and research.

(1) The definition and application of C2 scope. The C2 of a fighter aircraft or a battle carrier group is very different from the C2 of a corps or a 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 selected and discipline must be applied throughout model development.

(2) Multiple application of C2 models to analysis, training, and operational requirements. The relative constancy of C2 phenomena across this spectrum leads to the challenge of developing C2 models which can be used to support analysis, training, and operational requirements.

(3) 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 level the available resources across the breadth and depth of the problem.

(4) Basic research in the modelling of C2 into a number of areas should be supported. These areas include OOTW, IO, and the cognitive processes involved in human decision making. In this light, a follow-on SAS working group should be established to study such modelling and related analyses.

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GLOSSARY OF TERMS AND ACRONYMS

ACCES	- Army Command and Control Evaluation System; a derivation of HEAT developed primarily for joint theatre level operations, incorporating army doctrinal language and doctrine while sharing the same philosophy as its predecessor.
Adaptive Control	- In C2 systems, a mechanism to enable a system to exercise control over its environment through pre-planned, contingent responses to changes in a situation.
AHWG	- Ad Hoc Working Group
AI	- Artificial Intelligence
Approved Scenario	- A scenario adopted by the political and military community.
Automatable Decisions	- Or ‘simple decisions’, for which the range of options is finite and known and the criteria for selecting among them are clear.
C2	- Command and Control
C3I	- Command, Control, Communications, Intelligence
C4ISR	- Command, Control, Communications, Computers, Intelligence, Surveillance, Reconnaissance
CCIS	- Command, Control and Information System
COBP	- Code of Best Practice
Complex Decisions	- Require the decision making system to not only recognise when a decision needs to be made, but also (a) identify the relevant set of

options, (b) specify the criteria by which they will be judged, and (c) determine when the decision would be made.

Contingent Decisions	- Those decisions for which a set of alternative actions have been pre-determined and are appropriate to the situation, but battlespace developments and new information will be needed to resolve which is the proper course of action.
COTS	- Commercial Off The Shelf
CPX	- Command Post Exercise
DP	- Dimensional Parameter; the properties or characteristics inherent in the physical C2 systems. Examples include bandwidth of communications linkages, component size, number and variety of wavebands and luminosity of display screens in command centres.
DRG	- Defence Research Group (NATO)
HEAT	- Headquarters Effectiveness Assessment Tool
Integrated Analysis	- Used to define the key dimensions relevant to C2 analyses and explore the relationships between them (e.g. time, uncertainty, etc.).
Intelligent Control	- In C2 systems, a mechanism to enable a system to exercise control over its environment through either a tailored, proactive action that takes advantage of the factors at work in the operating environment, or one that responds to a predicted change in that operating environment.
IO	- Information Operations; information dominance over opposing forces, and its military application (from pre- to post-hostilities) of Command and Control Warfare, where the aims are to influence, degrade, or destroy adversary C2 capabilities and information links, while using countermeasures to protect one's own C2 assets.
MAUT	- Multi-Attribute Utility Theory; similar to ACCESS, but differs in that it assigns a utility component for each element and node in the

hierarchy. MAUT results should always be assessed by sensitivity analyses.

MCES - Modular Command and Control Evaluation Structure; an analysis framework for the measurement of performance and effectiveness within a conceptual model for C2.

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

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

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

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

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

MORS - Military Operations Research Society

NC3A - NATO Consultation, Command, and Control Agency

OA - Operational Analysis

OODA - Observe, Orient, Decide, Act; in reference to Boyd’s ‘OODA loop’ which emphasises speed in C2 systems.

OOTW - Operations Other Than War

Operational Scenario	- A scenario for combat analysis purposes, for which additional details are added to the planning scenario elements, especially with respect to threats, orders of battle, tactics, ROEs, courses of action, deployment, and reserves.
OR	- Operations Research
ORBAT	- Order of Battle
Planning Scenario	- A scenario for planning analysis purposes, in which the scenario parameters are described in detail.
ROE	- Rules of Engagement
RSG	- Research Study Group
SAS	- Studies Analysis and Simulations
Scenario	- A description of the area, the environment, means, objectives and events related to a conflict or a crisis during a specified time frame suited for satisfactory study objectives and the problem analysis directives.
Sensitivity Analysis	- The primary tool for assessing risk and uncertainty in OR research. It establishes the regions of stability for which the results are valid and isolates those factors that may be introducing uncertainty.
SHAPE	- Supreme Headquarters, Allied Powers, Europe
STA	- Surveillance and Target Acquisition
TRAC	- TRADOC Analysis Centre
TRADOC	- Training and Doctrine Command
TTP	- Tactics, Techniques, and Procedures

VV&A	- Verification, Validation, and Accreditation
VV&C	- Verification, Validation and Certification

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TERMS OF REFERENCE

I. ORIGIN

1. On 7 November 1991, NATO Defence Research Group Panel-7 established an Ad Hoc Working Group (AHWG) to study the modelling of Command, Control, Communications, and Intelligence (C3I). The specific charter of the AHWG was "To examine the extent to which the improvement brought about by the provision of better C3I to the commander can be quantified by present analytical means. The study should endeavour to produce measures of effectiveness for C3I which could be used to compare the improvement in combat performance offered by improved C3I with the improvement other investments might make. Attention should also be given to identifying how future studies might be conducted using enhanced analytical means. The study should be set in a post-CFE European scenario and consider land tactical operations. It should complete its work within a two-year time frame."

2. The AHWG met regularly for a period of 24 months as the basis for fulfilling its charter. National representatives from Canada, France, The Netherlands, The United States, The United Kingdom, and the SHAPE Technical Centre made technical contributions to the AHWG.

3. The AHWG found that limited capability exists among the participating nations to model C3I systems. Each nation provided samples of their major models and methodology materials which were evaluated by the AHWG. The evaluations revealed that the various models have limited applicability, and each reflects the priorities of the model developer. The results of this evaluation are documented in NATO DRG Technical Report AC/243 (Panel-7) TR/4 dated 21 Feb 94. The more significant shortfalls in the ability to analyse C3I systems noted in the report are:

(1) Absence of a common evaluation methodology;

(2) Lack of an agreed hierarchical set of Measures of Effectiveness for C3I systems;

(3) The integration of C3I processes with sensor and weapon (the so called hunter-killer system) is poorly represented, if at all;

(4) The degrees of detail in the elements at a given level of simulation are often not the same (C3I systems and processes are often represented with less detail than are weapon systems), and;

(5) There is often a lack of consideration of dynamic decision making and of human factors.

4. The AHWG was unable to produce an overall C3I evaluation methodology or to recommend specific enhancements to support future studies before the expiration of its 24 month charter. The AHWG recommended that a Research Study Group (RSG) be formed to complete the actions. Panel-7 approved the formation of the RSG at its April 1994 meeting.

II. MILITARY BENEFIT

5. The research will produce the analytical tools and techniques which will allow the study and evaluation of the contribution of C3I systems on the battlefield and in operations other than war. The results of the evaluation will provide the military with information to support investment decisions regarding the fielding of current and new technologies. The studies and evaluations will also provide information for deriving investment strategies based on the combat value of C3I systems versus other battlefield investments.

III. OBJECTIVES AND GOALS

6. The aim of the RSG is to assist NATO nations in the procurement of C3I by developing a standard methodology and code of best practice. This development will enable the contribution of C3I to military operations to be compared with other investments and will be promoted as an acceptable standard for this purpose within ministries of defence. In order to satisfy the aim of the RSG, three goals must be accomplished and are described below.

(1) To encourage basic and applied research into C3I modelling. The method of work will be to capture the results of completed and ongoing national studies and model development activities, to evaluate these (using the framework developed by the AHWG), and to derive information concerning C3I modelling techniques. This will be achieved by:

(a) Outlining methods/techniques to identify C3I information flows and information requirements, C3 organisations and their impacts, and the impact of information uncertainty;

(b) Studying the integration of the C3I processes with sensors and weapons (the Hunter/Killer process);

(c) Determining how C3I assessment requirements impact the selection of scenarios, and;

(d) Developing preferred practices, methodologies, measures of effectiveness and techniques for selecting scenarios in C3I evaluations.

(2) To identify the best practice in C3I modelling. This would be achieved by:

(a) Identifying a hierarchy of measures of effectiveness that are related to mission accomplishment and force effectiveness;

(b) Identifying current best practice C3I model design methods and standards, establishing a methodology for C3I models, including details of requirements capture and validation processes;

(c) Providing guidance on the construction of scenarios that are adequate for C3I evaluations. The guidance will include techniques that can be used to capture the C3I issues at combined and joint echelons and associated with multinational forces;

(d) Distributing the methodologies and encouraging those working in or with the RSG to utilise them and provide feedback on their applicability, and;

(e) Encourage users of force-on-force models to incorporate the methodologies.

(3) To disseminate the results of this research. This would be achieved by:

(a) Establishing seminars, informal discussions, and meetings for those involved in C3I modelling, and;

(b) Sponsoring the submission of material to conferences and appropriate magazines or periodicals, where it would raise awareness of modelling work in the C3I community.

IV. SCOPE

7. The RSG will use the framework and the insights developed by the AHWG as a starting point. The focus of the RSG effort will be on ground forces at the operational and tactical echelons. The C3I aspects of higher echelons, Joint and Combined forces that impact the land forces, will be included as required. The RSG will address the C3I aspects of military operations in both wartime and in operations other than war. Typical operations other than war include disaster relief, national assistance, security and advisory assistance, counterdrug operations, arms control, treaty verification, support to domestic civil authorities, and peacekeeping.

V. PRODUCTS

8. One major product will be delivered by the RSG : a draft code of best practice for C3I evaluations, distilled from member nation experiences and refined by the RSG. This code of best practice will also include a description of currently available models together with their data requirements, examples of use, and their strengths and weaknesses as well as measures of effectiveness, scenarios, and evaluation methodologies or philosophies used by the member nations for C3I evaluations.

VI. DURATION

9. The overall duration of the RSG will be two years. At the end of this period, a report summarising recommendations concerning current best practice will be available.

VII. RESOURCES

10. RSG will be chaired by the United States. The following countries have indicated a desire to participate: Canada, Denmark, France, The Netherlands, Norway, Spain, Turkey, The United Kingdom and the United States. The SHAPE Technical Centre (now NATO Consultation, Command, and Control Agency) will be invited to participate.

VIII. SECURITY LEVEL

11. The security level is up to and including NATO Secret.

IX. LIAISON

12. The liaison will later be determined.

SUMMARY OF WORKSHOP MINUTES

I. MINUTES OF NATO PANEL-7 RESEARCH STUDY GROUP-19 ON MODELLING OF C3I WORKSHOP ON MEASURES OF EFFECTIVENESS FOR COMMAND AND CONTROL, LONDON, ENGLAND - 10 JUNE 96

A. Executive Summary

1. A workshop on Measures of Merit for C2 Assessments was held 10 June 1996 in conjunction with the second meeting of the NATO Panel-7 Research Study Group-19 (RSG-19) on Analysis and Modelling of C2 that took place in London, England 10-12 June.

2. The goals of the workshop were to present and discuss the state of the art for command and control measures of effectiveness, with the ultimate aim of providing material for the final report of the RSG for the code of best practice.

3. In total, five presentations were given at the workshop. The presentations covered topics such as MCES and MORS philosophy, adaptation of C2 organisations to change, HEAT/ACCES methodologies, Task Force XXI Advanced Warfighting Exercise, and C2MOE Handbook and MORS C2 Evaluation Workshop. The presentations generated a great deal of interesting discussions.

4. The program was opened by an introduction given by the workshop coordinator, Mr. Valdur Pille from the Canadian Defence Research Establishment Valcartier. A synopsis of the workshop results was given by Mr. Pille at the close of the first day of the RSG meeting. Mr. Pille commented that one of the most challenging issues in C2 appeared to be the modelling of human behaviour. In addition, he noted that existing methodologies all have simplistic “block” approaches, but a crucial issue remains as to how these are to be implemented in analysis and modelling. Mr. Pille summarised the major accomplishments of the workshop as follows:

(1) While a single methodology may not be immediately definable for C2 MoE, the TRADOC and MCES methods have much in common and have a solid basis for the core approach of the code of best practice;

(2) The addition of another category of MoM, Measures of Policy Effectiveness, should be further considered. However, this is a peripheral measure which may be beyond the scope of military C2 effectiveness;

(3) The higher levels of MoM are scenario dependent and therefore, must be linked to the scenarios;

(4) The issues of types of measures (time, accuracy, etc.) and reliability/validity remain to be addressed, and will be included in the draft outline of the MoE section of the code of best practice;

(5) MoE is the commonly used terminology, however, the term "Measures of Merit" (MoM) should probably be adopted.

5. At the end of the discussion, the members agreed that sufficient information was available from the workshop to allow completion of the initial draft of the MoE section of the code of best practice. The general consensus was that the MoE information should be synthesised within the framework of the MCES. Canada volunteered to draft the MoE section.

II. MINUTES OF NATO PANEL-7 RESEARCH STUDY GROUP-19 ON MODELLING OF C3I WORKSHOP ON SCENARIOS FOR C3I ASSESSMENTS KJELLER, NORWAY - 7 OCTOBER 96

A. Executive Summary

6. A workshop on Scenarios for C3I Assessments was held 7 October 1996 in conjunction with the third meeting of the NATO Panel-7 Research Study Group-19 (RSG-19) on Analysis and Modelling of C3I that took place in Kjeller, Norway 7-9 October.

7. The goals of the workshop were to review the latest information and current best practice in scenario development for C3I studies among NATO and to discuss scenario selection with subject matter experts.

8. In total, twelve presentations were given at the workshop. The presentations covered topics such as an approach to scenario development in OOTW, an approach to scenario development in general, practices in scenario development, a strategy for formulating and exploring the scenario space, a service protected evacuation scenario, addressing C3I issues with scenarios, scenarios planning situations, scenarios and conception, scenarios for C3I studies, C3I requirements and scenarios, scenarios for use with general combat models, and scenarios in support of air defence systems. The presentations generated a great deal of interesting discussions.

9. The program was opened by an introduction given by the workshop coordinator, Mr. Ries Van de Scheur from the Netherlands TNO Physics and Electronics Laboratory. A synopsis of the workshop results was given by Mr. Van de Scheur on the second day of the RSG meeting. Mr. Van de Scheur summarised the major accomplishments of the workshop as follows:

(1) There is general agreement that scenarios are absolutely necessary to provide drivers for C3I studies;

(2) There is consistency and agreement among member nations as to what features should be included in an appropriate scenario such as:

a) Definition of command relationships and organisational structures, force structure and capabilities, information flows, communications layout, C3I systems involved, human in the loop, etc.

(1) There appear to be some minor differences among nations about definitions and classification of scenarios.

(2) There is a need for developing more scenarios for information operations and joint/combined operations.

(3) There are no fundamental differences in scenarios dealing with a variety of warfare domains; they all have common characteristics.

(4) Particular attention needs to be paid to the links between scenarios, MoM, and models.

10. At the end of the discussion, the members agreed that enough material has been assembled to attempt a first draft of the scenario section of the code of best practice.

III. MINUTES OF NATO PANEL-7 RESEARCH STUDY GROUP-19 ON MODELLING OF C3I WORKSHOP ON C3I SYSTEMS, STRUCTURES, ORGANISATIONS, AND STAFF PERFORMANCE EVALUATIONS, ISTANBUL, TURKEY - 17 FEBRUARY 97

A. Executive Summary

11. A workshop on C3I systems, structures, organisations, and staff performance was held 17 February 1997 in conjunction with the fourth meeting of the NATO Panel-7 Research Study Group-19 (RSG-19) on Analysis and Modelling of C3I that took place in Istanbul, Turkey 17-19 February.

12. The goals of the workshop were to review the latest research information available in evaluation of C3I systems, structures, organisations, and staff performance among the member nations, and to discuss the applicability of the information presented to the code of best practice (COBP) that is being developed by the RSG.

13. In total, nine presentations were given at the workshop. The presentations covered topics such as the interoperability of C3I systems, the C3I architecture design process, the use of simulated digitised command post exercises to evaluate staff performance, general structure of C3I systems, Pertinent evaluations of C3I organisations, and representation of C3I organisations in operations research type studies. Most of the presentations generated a great deal of interesting discussions.

14. The program was opened by an introduction given by the workshop coordinator, Mr. Tor Langsaeter from the Norwegian Defence Research Establishment (NDRE). All the member countries attended the workshop. Some countries had multiple representatives and thus gave several presentations. A synopsis of the workshop results was given by Mr. Langsaeter on the second day of the RSG meeting. Mr. Langsaeter summarised the major accomplishments of the RSG workshop as follows

(1) Identified major methodological problem areas for analysis and modelling of C2 organisations;

(2) Received an overview of current approaches for describing and modelling organisations in the C3I context, and;

(3) Identified promising approaches for problem areas.

15. At the end of the discussions, all the members agreed that enough information had been exchanged and that sufficient material had been assembled by the RSG to start drafting

the section dealing with C3I organisational aspects for the code of best practice. Mr. Langsaeter (Norway) volunteered to draft this section.

IV. MINUTES OF NATO PANEL-7 RESEARCH STUDY GROUP-19 ON MODELLING OF C3I WORKSHOP THE HAGUE, NETHERLANDS - 7-8 JULY 97

A. Executive Summary

16. A workshop on modelling of C3I was held 7-8 July 1997 in conjunction with the fifth meeting of the NATO Panel-7 Research Study Group-19 (RSG-19) on Analysis and Modelling of C3I that took place in The Hague, Netherlands 7-10 July.

17. The goals of the workshop were to identify the general issues of current and future modelling of C3I across member nations, to summarise current C3I modelling approaches, to identify promising C3I modelling approaches for inclusion in the SAS-002 Code of Best Practice, and to focus the organisation/structure of the SAS-002 C3I Modelling Symposium to be conducted in 1998.

18. In total, presentation were given by seven different participating countries and the NC3A, covering sixteen different models or modelling approaches. The presentations included the full gamut of models, including performance and effectiveness models, object oriented and procedure oriented models, and models of company through echelons above corps. The presentations generated much interest and discussion.

19. The program was opened by the co-chairmen for the workshop, Dr. Jim Moffat from the UK and Mr. Don Kroening from the US. Each nation presented both a general overview of the status of C3I modelling within their nation and detailed presentations regarding specific C3I modelling approaches. The workshop co-chairmen synthesised the results of the presentations and discussions and summarised the workshop results at the SAS-002 general meeting on 9 July. This summary included an identification of emerging best practices for C3I modelling and identification of the strengths and remaining challenges for C3I modelling across member nations.

BRIEF HISTORY OF RSG-19

I. BACKGROUND

1. On 7 November 1991 NATO Defence Research Group Panel-7 established an Ad hoc Working Group (AHWG) to study modelling of Command, Control, Communications, and Intelligence (C3I). The goals of the AHWG were to:

(1) Produce measures of effectiveness;

(2) Identify the use of enhanced analytical means in the conduct of future studies.

2. The study was to be set in a post-CFE European scenario and consider land tactical operations.

3. A major finding of the AHWG was that limited capability exists among the participating nations to model C2 systems. The AHWG was, however, unable to produce an overall C2 evaluation methodology or to recommend specific enhancements to support future studies. The AHWG recommended formation of a Research Study Group (RSG) to complete its actions. The formation of NATO Panel-7 Research Study Group-19 (RSG-19) on Modelling of C2 was approved by Panel-7 at its April 1994 meeting.

4. RSG reviewed the AHWG results and the reasons the AHWG was unable to complete tasking. Among those reasons were: too broad of a scope, focusing on C2 performance rather than on the relationship of C2 to other systems and organisations, and focusing on capabilities of existing models rather than on the development of global measures of effectiveness, organisational impacts, and the relationships among C2 and other combat systems.

II. RSG-19 MEETINGS AND WORKSHOPS

5. The planning meeting for RSG-19 was held on 3-5 October 1995 in Paris, France. Prospective members of the RSG and in attendance were Canada, Denmark, France, The Netherlands, Norway, Shape Technical Centre, the United Kingdom, and the United States. Mr. Fernando Payan of the United States was selected as Chairman. Turkey joined the RSG in February 1996, and Spain in June 1996. The Chairmanship passed from Mr. Fernando Payan (US) to Mr. Robert Bennett (US) in January 1997.

6. At this meeting, the group undertook a review of the RSG-19 Terms of Reference (TOR) and Program of Work (POW). The group determined that the primary product of RSG-19 was a Code of Best Practice (COBP) for modelling of C2. The RSG was to be in existence for two years and would hold three meetings a year. Each meeting was to be organised around a central topic which would be the focus of presentations and panel discussions for that meeting. In addition, it was envisioned that the RSG would conduct at least 4 workshops where each workshop would address a major section of the COBP.[1]

7. In 1996, meetings were held in Monterey, California, USA (February), London, England (June), and Kjeller, Norway (October). In 1997, meetings were held in Istanbul, Turkey (February), The Hague, The Netherlands, (July), and Quebec, Canada (October). In 1998, meetings were held in Madrid, Spain (February) and Copenhagen, Denmark (July).

8. Workshops were conducted in conjunction with four of the meetings. The London meeting featured a workshop on measures of effectiveness conducted by Canada, the Kjeller meeting, a workshop on scenarios conducted by The Netherlands, the Istanbul meeting a workshop on C2 systems, structures, organisations and staff performance evaluations, conducted by Norway, and the meeting at The Hague featured a workshop on C2 models conducted jointly by the UK and the US.

9. In January 1998, Panel 7, the parent body of RSG-19, was disbanded and its activities assumed by the new Studies, Analysis, and Simulations (SAS) Panel which operates under the auspices of the NATO Research and Technology Board (RTB). As a result, NATO Panel 7 RSG-19 was redesignated as RSG SAS-002.

10. In May 1998, the SAS Panel announced the termination of SAS-002 as of 31 July 1998. The RSG would, however, continue to exist as SAS-105 for the purpose of planning and conducting the January 1999 SAS Symposium on Modelling and Analysis of Command and Control, to be held in Paris, France.

A. Monterey Meeting

11. At the initial meeting in Monterey, each nation identified their models and studies to be included, and briefed selected models and studies to the group. This provided the group some idea of the areas of expertise of the members and how they could best contribute to the development of the COBP. The focus of the meeting was on measures of effectiveness

[1] Research Study Group on Modeling of Command, Control, Communications, and Intelligence Systems, Program of Work, 1 December 1996

(MOE), scenario development, modelling of C2 organisations, and the proposed outline for the COBP.

12. At this meeting the group agreed that the following steps were needed in a good C2 analysis:

(1) Define the warfare domain;

(2) Define C2 issues;

(3) Define or select scenarios consistent with the domain and issues;

(4) Define C2 systems and organisations in the scenario context;

(5) Define measures of merit (e.g., performance and effectiveness);

(6) Select, modify, or develop a model to quantify the measures, and;

(7) Run the model and analyse the outputs.

13. The subsequent meetings generally followed the format from the draft Program of Work in addressing these topics. Workshops were organised by members based on their areas of expertise, and those members were accordingly assigned to draft the corresponding sections of the COBP. Also at each meeting, members provided presentations on their nation's efforts in the focus area.

B. London Meeting

14. The focus of the second meeting in London and subject of the workshop was Measures of Merit (MOM). Canada conducted the workshop. The presentations at the workshop fell into the categories of general philosophy, selected applications, and discussions. As a result of this workshop, Canada was assigned the MoM section of the COBP.

C. Kjeller Meeting

15. The focus of the third meeting in Kjeller was a workshop, conducted by The Netherlands on scenario development and the proposed outline for the measures of merit section. The workshop identified common threads through national practices and members agreed that the first draft of the scenario section could be assembled. The Netherlands was assigned this section of the COBP.

D. Istanbul Meeting

16. The focus of the fourth meeting held in Istanbul was on organisations and included a one-day workshop on C2 systems, structures, organisations, and staff performance evaluations. The workshop, conducted by Norway, identified major methodological problem areas for analysis and modelling of C2 organisations, provided an overview of current approaches for describing and modelling organisations in a C2 context, and identified promising approaches for problem areas. Norway volunteered to draft the organisational section of the COBP.

E. The Hague Meeting

17. The focus of the fifth meeting held in The Hague was a two-day workshop, conducted jointly by the UK and the US, on models used for C2 systems and analyses. The major workshop accomplishments were:

(1) A review of the modelling approaches among RSG-19 members;

(2) An assessment of strengths and weaknesses of current and evolving/planned models;

(3) The identification of evolving Information Operations modelling and simulations requirements, and;

(4) A synthesis of commonly accepted practices with some implications for focusing the C2 symposium, and for drafting the modelling section of the COBP.

18. All members agreed that they had enough information to start drafting the C2 Modelling section of the COBP. The US and the UK volunteered to jointly draft this section.

F. Quebec Meeting

19. The focus of the sixth meeting held in Quebec was to work out the final outline of the COBP and review the four sections currently in draft. The major accomplishments of this meeting were:

(1) Members agreed to general layout and detailed content of some sections of the COBP;

(2) Measures of Merit, Modelling and Simulations, Organisational aspects sections were reviewed, and;

(3) Status of the scenario section was discussed.

G. Madrid Meeting

20. The major objective of the Madrid meeting was to produce the first complete working draft of the COBP. At this meeting, the RSG finalised the general outline of the COBP and reviewed and revised all the drafted sections. This resulted in the first complete working draft of the COBP along with a strategy to draft the few pieces remaining unfinished at the close of the meeting.

H. Copenhagen Meeting

21. The objective of the Copenhagen meeting was to review the completed draft of the COBP and develop recommendations for the final editing. This was accomplished by providing the Chairman with comments for inclusion in the final document.

III. SUMMARY

22. In summary, workshops were conducted on Measures of Effectiveness (CA), Scenario Development (NL), C2 Systems, Structures, Organisations and Staff Performance Evaluations (NO), and Models Used for C3 Systems and Analysis (US/UK). In addition, the group decided not to include cost analysis as part of the COBP because they felt that they did not have the proper expertise and it would take too much time to come to grips with all the costing issues.

IV. RSG-19 FOLLOW-ON

23. At the July 1997 meeting, in response to a query by Panel-7, the group discussed the need for a follow-on effort to that of RSG-19. The members acknowledged and agreed on the need for follow-on group after RSG-19 ends. Initial Terms of Reference for this follow-on group were discussed. The group strongly felt that the follow-on group should focus only on two or three topics and limit its scope. The Chairman recommended that the number one focus of the follow-on group be Operations Other Than War (OOTW), and that this group also take on Information Operations if there is sufficient time and resources.

24. At its May 1998 meeting, the SAS Panel decided to create an Exploratory Team to investigate the benefits of establishing a follow-on RSG to expand the SAS-002 Code of

Best Practice with the goal of defining the scope of work to be completed by the follow-on group. The Exploratory Team would be composed primarily of members from SAS-002 and will be tasked to complete its work at the end of 1999.

C2 EVALUATION METHODOLOGIES

I. MCES

1. 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 effect of C2 on combat.

2. 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 leaves the details of the measurement, data collection, and analysis plans to the analyst.

3. MCES considers Command and Control as consisting of three components: physical entities (equipment, software, people), structure (interrelationships of entities), and processes (C2 functions), with the boundary of a C2 system being defined as a delineation between the system studied and the environment. [The TRADOC C2 MoE Handbook adds mission objective as the top layer of the hierarchy of C2 components.]

4. MCES focuses on measures as opposed to models, but includes the generic command and control loop. Table 1 lists the seven MCES procedural steps.

Table 1 MCES Steps

Step	Procedure	Product
1	Formulate the problem	Problem Statement & Scenario
2	Bound C2 system	System Elements
3	Define C2 process	System Functions
4	Integrate elements and functions	System Architecture
5	Specify measures at boundaries	Functional Measures
6	Generate data for measures	Values
7	Aggregate and integrate results.	Analysis of Results

A. Problem Formulation

5. This module provides a description of the analysis objectives from the viewpoint of the life cycle of the C2 system, and the level of analysis prescribed. Assumptions are stated, and the scenarios selected.

B. C2 System Bounding

6. The system elements are identified and categorised, and the C2 system of interest is bound in terms of physical entities (equipment, software, staff), structure (organisation, concepts of operation), and C2 processes. The boundaries are identified in terms of subsystems, C2 systems, own forces, and the environment.

C. C2 Process Definition

7. The functions of the C2 process are identified and mapped to the generic C2 cycle (sense, assess, generate, select, plan, direct), and the inputs and outputs to the processes are identified. Insight to C2 is obtained by decomposing the C2 cycle into functions/ subfunctions, processes, and tasks. These are situation independent descriptions of responsibilities of the elements constituting the military organisation. The high level functions of Monitor, Assess, Plan, and Direct further decompose to sub functions. The term processes in this context define the interrelationships of tasks that are performed to fulfil the functions.

D. Integration of Elements and Functions

8. This module defines the relationships between the C2 processes, physical entities, and structure. Input/output relations are derived to describe the internal information flows between separate process functions, and physical entities which perform functions are mapped to the outputs. The hierarchical relationships between C2 functions are determined, and an organisational structure is produced.

E. Specification of Measures

9. This module results in the specification of measures focused primarily on the C2 process functions. The measures are classified according to the four levels previously defined. The MCES defines the following attributes for MoM:

(1) Name and category;

(2) System reference (boundary);

(3) Function reference (purpose);

(4) Units of measure;

(5) Value measured, and;

(6) Threshold value (goal).

F. Data Generation

10. The generation of values for the identified measures may be accomplished by various means such as exercises, experiments, simulations, subjective judgements. The values may be measured directly, or be derived from other measures. For the evaluation of new systems, the generation may be assisted by designing into the system functions to yield specific measurements.

G. Aggregation of Measures

11. For the aggregation and analysis, particular attention must be placed on the causality, sufficiency, and independence of measures.

II. ACCES - ARMY COMMAND AND CONTROL EVALUATION SYSTEM

12. ACCES is a derivation of HEAT (Headquarters Effectiveness Assessment Tool), 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 measurements 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 command and control process, from the collection of data to the conversion of data to intelligence, and to the implementation of plans and directives. The underlying approach to ACCES is that command and control comprises interdependent sub-process which can be observed and measured. ACCES considers C2 as an adaptive control process, where information collected from the outside is processed internally for generation of plans, which may be adapted to 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 remains in effect throughout its intended life. ACCES yields measures corresponding to the MORS MoE level of hierarchy. Table 2 lists the core measures according to the C2 cycle.

Table 2 ACCESS Measures (1 of 3)

MONITOR	
Completeness	Commander's Information List Requirements (CILR) for which there are data
Accuracy	Units or CILR items for which headquarters data are within the desired window of accuracy
Querying	Units where most recent data are outside the desired time window and the data was queried
Timeliness	Units for which the most recent data are within the desired time window
Impact on plan	Control cycles initiated because of monitoring errors
Forecast correctness	Predictions of time at which change in weather and terrain will occur that are correct

Table 2 ACCESS Measures (2 of 3)

ASSESS AND UNDERSTAND	
Completeness	Periodic briefings requiring an understanding of the situation to be expressed, at which the understanding is actually stated.
Quality	Perceptions of the situation held by the headquarters, scored as percentage correct, not incorrect, or incorrect.
Impact of plan	Control cycles caused because headquarters understanding did not match ground truth.
Understanding time	Time from the expression of understanding to the end of the period which the understanding covers.

GENERATE AND PREDICT	
Multiple options	Number of options considered
Multiple planners	Staff members who participate in the development of alternative course of action
Prediction completeness	Estimates that include, for each option presented, predictions of enemy reaction, degree of mission accomplishment, and residual capacity of friendly and enemy units involved.
Prediction quality	Predictions scored as "correct", "not incorrect" or "incorrect".
Prediction time	Time from the making of an estimate to the end of the time covered by the associated predictions.

DECIDE	
Plan quality	Plan assignments that remain in force unchanged for the intended period, expressed as a percentage of the total assignments. The assignments in a plan are: mission, assets, boundaries, and schedules
Plan congruence	Control cycles arising from minor, moderate, or major incongruence.

PLAN	
Time from decision	Time taken to issue a directive after a decision has been made
Plan consistency	Assignments in implementing directives which do not contradict a Commander's decision
Plan clarity	Directives not queried by recipients
Plan cycle time	Time used to complete the control cycle given minor, moderate, or major incongruence.

Table 3 ACCESS Measures (3 of 3)

DIRECT	
Plan lead time adequacy	Directives for which planning lead time provided to subordinates is adequate
Time induced aborts	Directives for which lead time is insufficient to permit a suitable response
Query response time	Queries responded to within the specified time

13. In addition to the above measures, ACCES includes two other sets of measures: coordination measures, which are used to assess how well the staff gather information within their command centre and with counterparts in other command centres; and report measures used to assess how well the command maintains communications with superior, subordinate, and adjacent commands.

III. MULTI- ATTRIBUTE UTILITY THEORY (MAUT)

14. MAUT, or Multi-Attribute Utility Theory, is similar to ACCES in the sense that both use functional decomposition and function specific evaluation metrics. The major difference is that MAUT assigns a utility component for each element and node in the hierarchy. MAUT then aggregates upwards the weighted scores to provide composite scores of effectiveness.

15. MAUT has been used by some practitioners to assess C2 in a particular context. MAUT is based on decision analysis and makes a variety of assumptions. The first is that the analyst knows all the factors that will influence performance. The second is that the analyst can properly weight those factors. Finally, MAUT assumes that the relationships between the independent and dependent variables are known and properly specified. MAUT is, therefore, like MCES -- it specifies a process for analysis but leaves the task of identifying appropriate C2 theory and measures to the analyst.

16. The four key components of the MAUT framework are stimulus, hypothesis, option, and response, which could be mapped onto the C2 cycle. These functions are overlaid into an evaluation methodology of three aspects:

(1) The interface between the system and user;

(2) The relationship between the user and the organisation, and;

(3) The interface between the organisation and the environment.

17. Measures specific to each of the above aspects are identified, aided by the decomposition into a hierarchy of processes, functions, tasks and activities. For each element and node in the hierarchy, a utility component is assigned in perspective of the overall evaluation goal. The MAUT approach does not consider all tasks and functions assessed to be of equal value and importance. Finally, the weighted scores are aggregated upwards to provide composite scores for each nodal function and interface domain to obtain a measure of overall effectiveness.

18. Ultimately, MAUT analyses are only as good as the measurement and theory underlying them. For well understood, narrowly focused problems, MAUT can be a powerful tool that both provides a sound structure for describing relationships and also permits a variety of sensitivity analyses. However, in poorly structured problems or weak knowledge domains, MAUT is simply a way of looking at the consequences of different sets of assumptions.

IV. “WHAT’S DIFFERENT” APPROACH

19. The foundation for the approach is an understanding of how the future command and control is expected to differ from today’s command and control. These differences can be said to occur in five broad areas: better battlespace visualisation, more adaptive decision making, more agile battle management, information enabled organisations, and significant increases in force effectiveness and efficiency. Table 3 depicts the benefits of these changes from a commander’s viewpoint and Table 4 depicts the attributes associated with the “What’s Different” areas along with a set of high level measures of merit that would be used to assess the contribution of a new system and/or doctrine and organisational changes towards the achievement of the “What’s Different” goals.

Table 3
Example Benefits of the Information Technology Revolution
From the Commander's Viewpoint

Better Battlespace Visualisation	Dispels most of the "Fog of War" Information uncertainty replaced with coherence
Information Enabled Organisations	Traditional HQ staff organisations—J1 to J6 are replaced or combined Faster, more complete staff processes
Adaptive Decision Making	Provides revolution in the scope and speed of decision making Make informed decisions inside the enemy's decision cycle
Agile Battle Management	Results in dramatic force agility increase versus the enemy Enables "Dominant Manoeuvre"—the essence of agility
Significant Increase in Force Effectiveness and Efficiency	Capable of larger mission accomplishment with smaller forces Seize and maintain the initiative

Table 4 What's Different—Measures of Merit (1 of 3)

Better Battlespace Visualisation	**MoM**
More complete, current and consistent	Completeness with respect to commander's requirements Age of information "Timeliness" of information Accuracy of information compared with ground truth Fidelity of information node-node
More comprehensible	User understands the information Compare utterances with ground truth
Flexible retrieval and presentation (pan, zoom, associate)	Accessibility of information—all nodes have access to needed information Time required to access information
Future explicitly considered	Prediction time
More explicit uncertainty management	Incomplete information is "flagged" Information is provided with "confidence" tags (compare confidence ratings with ground truth) Decision aids present adequate options
Information Enabled Organisations	**MoM**
Virtual teams	Number and variety of participants and locations Percent of tasks worked at multiple locations
More distributed information and processes	Percent of organisation on line, "up time," and volume of information available
Agile organisations	Frequency of recognising need for task reorganisation Time required for task reorganisation

Table 4 What's Different—Measures of Merit (2 of 3)

Information Enabled Organisations	**MoM**
More integrated across function, level of command, and time	Time to consult, coordinate and approve across functions, levels of command, and time into the future Age of information Query response time Percent of data used relative to data at work sites
Improved organisational learning	Time to recognise patterns and changes thereto Accuracy of pattern recognition Time to adapt to changing patterns Time to create new patterns through innovation Increased inputs to decision process
Adaptive Decision Making	**MoM**
Context driven decision process	Correct recognition of state change Speed of state change recognition
Imbedded, predictive decision support	Capability of decision support tools to generate and assess alternative futures and COA
Rapid plan/re-plan capability	Decision time for implementation of plan changes - were they implementable? "Goodness" of plans - need for change outside contingencies Correctness of predictions
Contingency rich COA analyses and plans	Number of contingencies analysed Number of contingencies built into plan Adequacy of contingencies
Agile Battle Management	**MoM**
Distributed , integrated, and more simultaneous coordination and consultation	Number and variety of participants and locations More correct decisions on complex problems Time to respond to requests
Highly responsive ISR capability	Increased self-tasking Time to respond to tasking Reduced unsuccessful tasking

Table 4 What's Different—Measures of Merit (3 of 3)

Significant Increase in Force Effectiveness and Efficiency	**MoM**
Seize and maintain the initiative - Shape the battlespace	Commander predicts future alignment of the battlespace After plan implementation and execution, friendly and enemy forces are aligned as predicted Percent planned high value targets destroyed within plan timeline Phase changes recognised
- Phase the campaign	Plan provides logical sequencing for campaign Sequencing is accomplished as planned Friendly informed decision cycle shorter than enemy decision cycle Plans are proactive, requiring enemy to react
- Control the pace of the battle	
Destroy the right targets	Overall casualties reduced Unintended targets damaged/total targets damaged compared to baseline Time to complete comparable operation Behavioural impact of fires and threats on organisations, operations, plans and individuals
Concentration of fires replaces concentration of mass	Compared to baseline for the same mission friendly forces have greater disbursal with fire effectiveness
More efficient use of communications and logistics systems	Percent reduction in bandwidth required Percent right material, right place, right time Percent supplies, material lost en route
Traditional battle outcome measures	Enemy killed/total enemy divided by friendly killed/total friendly Percent enemy total casualties/friendly total casualties Percent critical territory captured Percent planned mission accomplished

NATIONAL MODELLING PROGRAMS

I. INTRODUCTION

1. A number of nations (Canada, UK, US, Denmark, Norway, Netherlands, France), together with NC3A, gave overviews on the current status of representation of C2 in their modelling of Land or Joint (Land/Air) warfare. The picture which emerged was that representation of C2 processes was now recognised as a very important issue. It was now accepted in a number of countries that it was important to have a proper representation of the decision-making process, in order to link C2 performance to overall force effectiveness, and to represent ‘Information Operations’ effects such as Counter C3 or Digitization of the Battlespace.

II. UNITED STATES

2. Briefings were given on a number of extant constructive simulation models and wargames. VIC and CASTFOREM (at operational and tactical level respectively)are two of the key current simulation models used by the army analytical community (TRAC) in the USA. VIC is a Corps level model with a ‘Theatre slice’, it is a batch model with ‘interrupt points’ for people in the loop (PITL). They are both based on a philosophy of capturing decision processes using many interacting decision rules. Key recent improvements in VIC, include putting Headquarters on the game board (so that they can be attrited), and representation of the recognised picture (‘SITMAP’) in each such HQ, which forms the basis of subsequent orders and reports. Representation of communications in such ‘Force on Force’ models is being improved through standardising on OPNET for analysis. New developments are focused on the JWARS model. This will be a fully integrated constructive simulation model of joint warfare at the theatre/operational level. It is intended that it will have a proper representation of C2, including the activities of data fusion, picture compilation and the planning process. It will be developed in an evolutionary and object oriented manner. To complement such models, very fast running System Dynamic models (under the umbrella name of CAPE) have been developed which can run rapidly through a large number of options in ‘scenario space’ and identify critical areas for deeper analysis. A further approach being developed in the US is to combine models together in a federation, using a real time high level architecture (HLA). This allows current models (of logistics, the decision process, the warfighting process, etc.) to be combined in new ways to produce new ‘meta-models’.

III. DENMARK

3. The JOHANNES model at operational/tactical level represents a number of key decisions, based on decision options which are prescripted. The model represents the choice of option based on sensor information and decision rules for changing the missions of the fighting units.

IV. UNITED KINGDOM

4. Briefing was given on innovative research aimed at producing constructive simulation models incorporating the effects of C2, which run at rates very much faster than real time, and which are easily transportable across different scenarios. A number of constructive simulation testbeds (HiLOCA, CLARION+ (a development of CLARION) and MOSES) are being developed in an evolutionary and object oriented manner. These span Land/Air operations from OOTW to Theatre level. The aim is to develop a single representation of a generic HQ ,or command agent, in terms of both the object architecture and object functionality, with emphasis on data fusion, picture compilation and the planning process.

V. FRANCE

5. Two significant developments were briefed. The first (MATIS) is long term research in train on abstract representation of the decision-making process. The second CARNEADE) is a federation of command agents, together with people in the loop. CARNEADE has been in development for a number of years and is aimed at the study of C2 effects at the operational/tactical level. The agents are complex rule based representations, interacting in a richly represented, near real time environment.

VI. NORWAY

6. A briefing was given on the STASIM model. This is a performance level model whose overall Measure of Merit is the speed of the C2 process. Such MoM are used as input to Force on Force models, or to see whether performance thresholds from such Force on Force models are delivered by the C2 organisation.

VII. NC3A

7. The CASSANDRA model is a key development at NC3A. It is a constructive simulation at Theatre/Operational level of Joint Land/Air warfare. The approach is based on the UK CLARION development. The design is modular and object oriented. Initial

operational objectives are set at the strategic level, with some contingencies. These are translated in the model into tactical level missions assigned to units. Adaptive C2 is represented by ‘posture transition’ rules which act on the missions initially assigned to units, based on this overall campaign plan.

VIII. NETHERLANDS

8. The approach in to Netherlands is to develop very focused models for particular applications. Briefing was given of a model named SMART. This is a ‘hunter - killer’ model relating artillery tasks to ammunition requirements and allocation of artillery assets. Representation of the command posts allows consideration of aspects such as redundancy of information.

IX. CANADA

9. The briefing addressed a different perspective on modelling: data modelling for C2. Data modelling, in combination with process modelling, provides a means of documenting requirements and is considered an essential part of system implementation. Common data structures for C2 systems has been identified as the major practical means of achieving interoperability systems for joint and coalition forces. The Canadian Department of National Defense has elaborated an overall DND information management vision called the Integrated Information Environment (IIE) with the aim of the achievement of enhanced effectiveness and efficiency through information superiority. National Command and Control Information Systems are to conform to a Common User Core (CUC) which draws on the NATO Allied Command Europe Allied Command and Control Information Systems (ACE ACCIS) architecture and the Defense Integrated Information (DII) Common Operating Environment (COE) standards. The Canadian Forces Air Command in conjunction with the Defense Research Establishment Valcartier (DREV) is developing the Air Environment Data Model (AEDM). Future activities in data modeling at DREV will include the assessment of compliance with the NATO ATCCIS model, object-oriented database technology, distributed and replicated databases, and the functional decomposition of the Canadian Air Force C2 domain.

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