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Assessing the Military Worth of C4ISR Information

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Abstract

Assessing the military worth of C4ISR information is a topical and challenging problem for military operations and systems analysts – the development of appropriate techniques and models is still in its infancy. This paper reviews the issues surrounding the vexed question of 'How do you assess the military worth of C4ISR information?' then proposes a construct and some potential metrics for further consideration, development and testing. The approach starts with the general hierarchy for metrics developed by the Military Operations Research Society (MORS) as a framework then attempts to identify metrics at lower levels that may be readily amenable to evaluation but could also be used to assess higher-level (and usually qualitative) attributes such as timeliness, relevance, accuracy and comprehensiveness of information.

1. Introduction

The provision of timely and relevant information has always been fundamental to the successful conduct of warfare. What has changed in current times is the richness and reach of information that is now available to the military decision maker and the volume and speed at which it arrives. Information for military operations is now derived from many disparate sources. These sources can be categorized as:

- data from sensors,
- military intelligence and information from other human sources, and
- information published in the public domain including the various forms of the media.

This paper is concerned with the military information available to the military commander or decision-maker from the first two categories. This information is usually supplied through the Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) systems, which are fast becoming an integral part of a headquarters. The third category of information may also be readily available to the commander through these systems and their links to external information providers but we will not consider this category further.

Concepts of command and control, intelligence, surveillance and reconnaissance are as old as armed conflict itself but what is new are the modern technological means of achieving them – namely information technology and telecommunications (IT&T). The promises of the revolution in military affairs (RMA), heralded by the rapid advances in IT&T we are experiencing, are:

- the ability to undertake faster, more precise and more decisive military operations,
- an efficiency dividend from being able to achieve desired effects with smaller forces or overwhelming effects with current force sizes, and
- reduced administrative, logistical and operational and support overheads.

While the application of these new technologies is proceeding apace, the general questions arise 'How do you determine if improvements have been achieved?' and 'How do you tell if it was money well spent?' Competing budget priorities mean that proponents of particular systems have to be able to justify the expenditure of funds on C4ISR systems versus funds spent on platforms [Scott, 1998]. This, and the need to assess the impact of improvements in C4ISR systems, has lead to the considerable interest in measuring the military worth of C4ISR systems and the information supplied by them [Ballenger, 2001; Washburn, 2001a].

Of particular interest is the use of IT&T to bring together the information gathered by a variety of separate, and often disparate, command and control, intelligence, surveillance and reconnaissance systems into a militarily effective and useful C4ISR system. This will be the focus of our paper.

2. What is C4ISR?

While NATO, US DOD and ADO definitions exist for the elements of C4ISR,[1] there does not appear to be a formal definition for C4ISR in its entirety. One way of viewing C4ISR is as an aggregation of systems – command and control systems, intelligence services and surveillance and reconnaissance assets with telecommunications and information technology (i.e., communications and computers) as enablers of the overall system of systems (SoS) thus formed.

The following definition attempts to link such a system of systems concept to the military information capability sought:

> *'C4ISR is an aggregation of diverse command and control, intelligence, surveillance and reconnaissance elements that provide military information to a Commander and, when brought together with appropriate communication and computer networks, may be thought of as a virtual, enabling capability for military operations.'*

Assessing the military worth of information provided by a C4ISR SoS would then be central to determining the efficacy of the C4ISR SoS in military operations.

3. What are the Characteristics of a System of Systems?

A system of systems (SoS) is defined by [Krygiel, 1999] as 'a set of different systems so connected or related as to produce results unachievable by the individual systems alone'. The major characteristics that distinguish a SoS are that the individual component systems may be operationally and managerially independent, geographically dispersed and evolving separately but that when connected some properties emerge which allow the SoS to fulfill its purpose [Maier, 1996]. A SoS can therefore only carry out its purpose through the interactions between the

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[1] NATO is the North Atlantic Treaty Organization, US DOD is the United States Department of Defense and ADO is the Australian Defence Organisation.

individual systems. In particular, the passage of information between the component systems is fundamental to the effectiveness of the SoS. Interoperability, which is defined as the ability of two or more systems or elements to exchange and use information, is thus an essential requirement for an effective SoS.

C4ISR systems, comprising C2 systems, surveillance systems, intelligence systems, etc clearly fit into the category of SoS and thus the evaluation of their effectiveness should take into account the characteristics of SoS.

4. **A General Hierarchy for Metrics**

The NATO Code of Best Practice [AC/243, 1998] has adapted the hierarchy of metrics developed by the Military Operations Research Society (MORS) as the basis for their selection of measures of merit (MoM) for the evaluation of C2.[2] This hierarchy comprises:

- Measures of Force Effectiveness (MoFE) which focus on how a force performs its mission or the degree to which it meets its objectives. Prime examples are force and exchange (relative force losses) ratios.
- Measures of Effectiveness (MoE) which focus on the impact of C4ISR systems within an operational context. Examples could include communications survivability and resistance to countermeasures, ability to formulate and distribute plans or create a common operating picture.
- Measures of Performance (MoP) focusing on internal C4ISR system structure, characteristics and behaviour. Example would include sensor spatial coverage, network loading, target tracking and delays.
- Dimensional Parameters (DP) measure the properties or characteristics inherent in the physical C2 systems. Examples include bandwidth, signal to noise ratios, scan rate and field of view for sensors.

This hierarchy for metrics (illustrated in Figure 1) looks at the performance of C4ISR systems in terms of the system's ability to generate or collate information and provide it to the end user in a timely manner. It offers a broad construct for developing approaches to measuring the value of information in military operations. Measuring the performance of individual systems can be done with this hierarchy but to measure the effectiveness of a C4ISR SoS, concepts of hierarchy, emergent properties, communication and control from systems thinking should be included in the metrics used.

The question to be asked is not just how well a C4ISR system delivers information but 'How useful is the information that is made available?' It comes back to the old adage of 'the right information in the right place at the right time to the right person'. The time, place and person can usually be readily quantified and assessed. But what is the right information and then by extension how valuable is this information?

[2] C2 as used in the NATO Code of Best Practice encompasses all of the components of C4ISR.

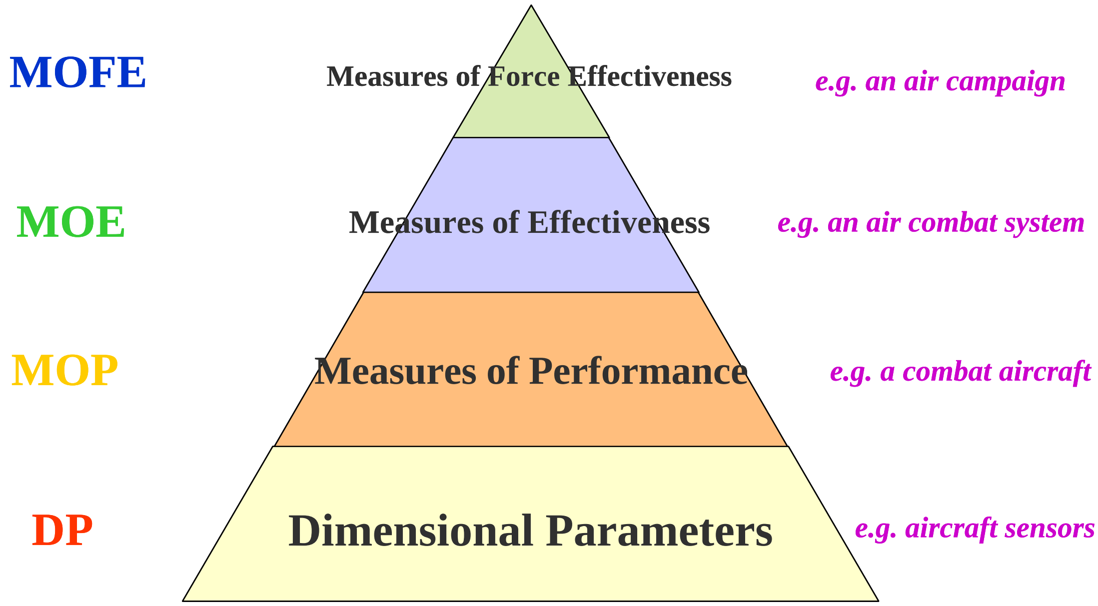

Figure 1. MORS hierarchy for metrics.

5. Assessing the Military Worth of Information

How to assess the military value of information *per se* is currently a vexed question. Fundamentals questions that arise include [Ballenger, 2001]:

- What is the value of information?
- Does it increase combat power and, if so, by how much? Also how can it be apportioned to an individual soldier, ship or aircraft?
- Is force ratio a useful metric for information capability? If so how does information affect force ratio? If not what should replace it?
- How does the type of information (location, number, size, speed, etc) affect its value?
- How do we factor in the quality of information?

Washburn [2001a; 2001b] recently reviewed existing approaches to evaluating the contribution of information to military operations and summed up the current maturity of techniques for assessing the military worth in following statement [Washburn 2001a]:

> *'It is clear to military professionals that information is becoming increasingly important, but the OR profession's ability to measure the contribution of information is still primitive. We are not good at deciding whether information is cost/effective or whether information is more important than firepower, and yet precisely these questions will be asked more and more frequently as budgets shrink.'*

He makes two important points about information valuation. The first is that information is of no value unless there is an uncertain decision-maker and the second is that information is of no value unless some decision-maker has the power to use it.

Seymour et al. [2001] have proposed a framework for a hierarchy of measures against which the benefits and costs of a networked C4ISR system can be assessed. Their analysis framework builds upon the premise that a C4ISR SoS is the principal enabler of the 'knowledge edge' that results from information superiority. In this framework they define a hierarchy of outcomes from data and information superiority at the lower levels, through knowledge and decision superiority, to 'effects superiority' at a force level. In this framework, C4ISR is divided into four elements: C2 (command and control), communications, computing and ISR (intelligence, surveillance and reconnaissance). The relative impact of these elements for transitions between the various levels of the framework is then described as low, medium or high. While the primary measures of a C4ISR system might be at a particular level, this framework enables the benefits achieved by a C4ISR system to be traced through to the force level and hence assessed against the military outcome sought. Development of the framework is ongoing using synthetic environment experiments.

The 'OODA Cycle' (observe-orient-decide-act) concept, illustrated in Figure 2, also relates obtaining and processing information to deciding and acting upon it and hence to military outcomes or 'effects' [Seymour et al., 2001; Moon, Kruzins & Calbert, 2002]. For an OODA Cycle, the observe and orient (OO) phases relate to the gathering, collating, processing, making sense of and presenting of information while the decide and act (DA) phases relate to command decisions, direction and actions resulting from consideration of the information presented. The OO phases may then be thought of as the 'inform' part of the OODA cycle and the DA phases as the 'respond' part.

The contemporary view is that information needs to be timely, relevant, accurate and

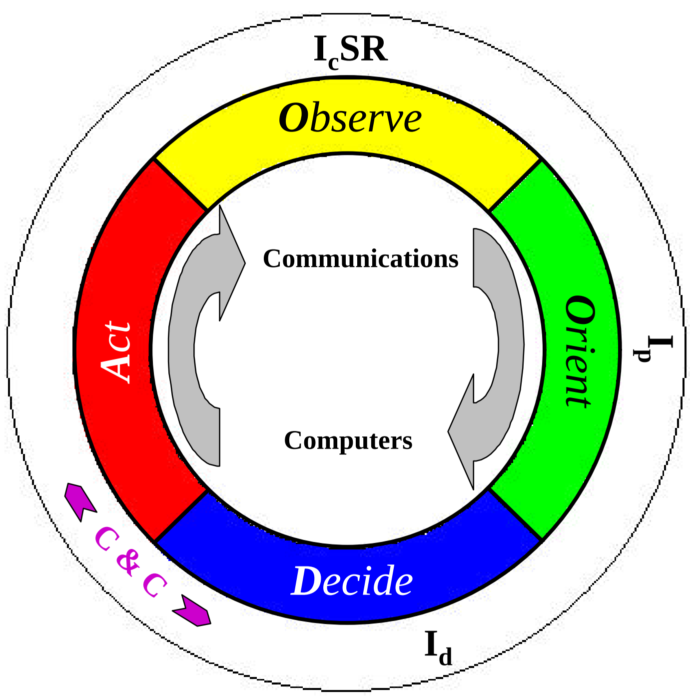

Figure 2. OODA Cycle concept. Here I_c is the collection phase of the intelligence cycle, I_p is the processing phase and I_d the dissemination phase. The direction phase would be included with command and control activities in the act phase of the OODA cycle.

comprehensive (TRAC). These 'TRAC' attributes could then be regarded as top-level metrics for the inform part of a C4ISR SoS. For the respond part the attributes of interest could be how swiftly, precisely, extensively and decisively (SPED) information is acted upon. While such attributes would help relate the quality of C4ISR information to military outcomes, assessing them is not straightforward. By themselves these TRAC and SPED attributes are not readily measurable. The question then is 'What can we measure to evaluate them?'

The metrics or measures of information quality to be used within these frameworks still need to be developed.

6. Metrics for TRAC Attributes

The following measures may provide tractable metrics for use in assessing the TRAC attributes of a C4ISR SoS at various levels of analysis, and for a variety of military operations. The proposed metrics could be considered as MoP with timeliness, accuracy, completeness and relevance forming the MoE at the next level up.[3] The overall ability of a C4ISR SoS to provide information that facilitates successful military operations then becomes the focus for appropriate MoFE. Proposed MoE and MoP for assessing the TRAC attributes of a C4ISR SoS are thus:

<u>Timeliness</u>, comprising:

- Speed of service
- Latency
- Frequency (or refresh rate)
- Perishability (or shelf-life)

<u>Relevance</u>, comprising:

- Criticality (or precedence)
- Paucity of knowledge of situation i.e., degree of uncertainty of a decision-maker.
- Usability i.e., ability (or power) of a decision-maker to use the information.

<u>Accuracy</u>, comprising:

- Number of independent sources contributing to or confirming information.
- Veracity of sources. (Could simply be the confidence in a particular source based on historical knowledge of what proportion of the time information from that source has proven to be correct.)
- Internal consistency of the information (measured through proportion of conflicting information).

[3] Timeliness, relevance, accuracy and completeness may then be amenable to assessment as MoE through their defined MoP.

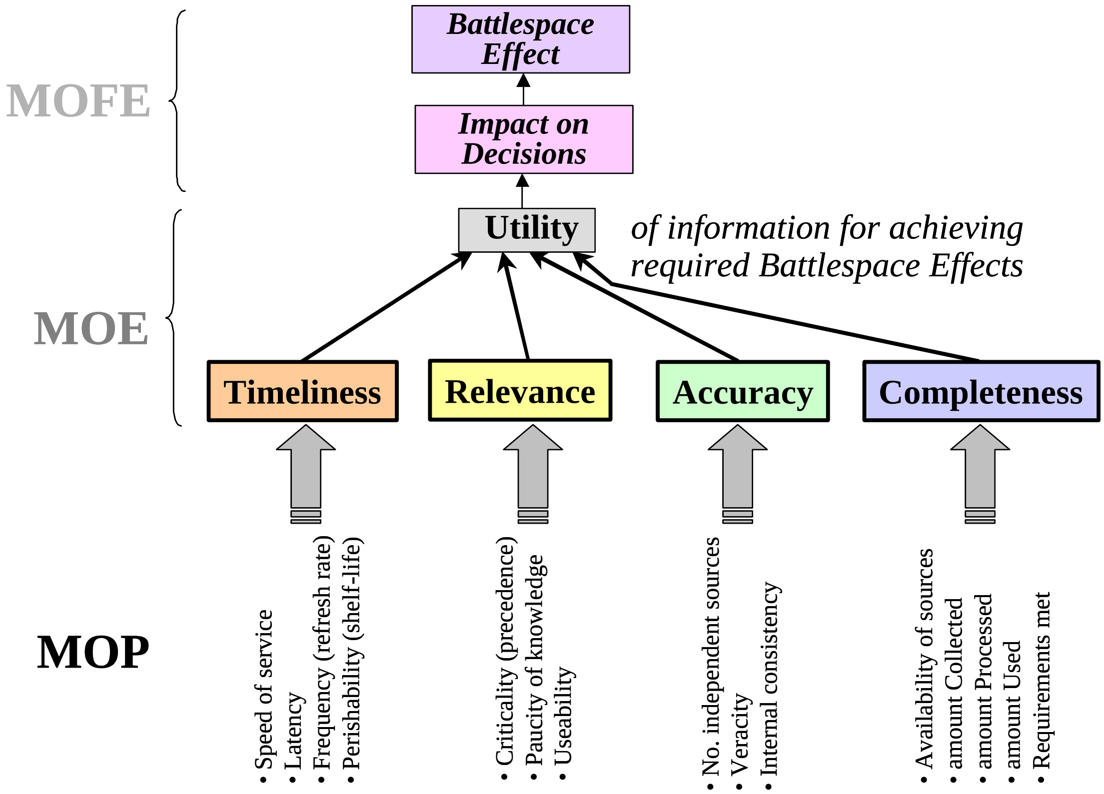

Figure 3. Metrics for assessing the military worth of information.

Completeness, comprising:[4]

- Availability of sources (proportion of connected sources on-line and available).
- Amount of information collected (proportion of the total information that could have been collected that was actually collected).
- Amount of information processed (e.g., proportion of collected information processed).
- Amount of information used by a decision-maker (proportion of processed information actually used).
- Amount of critical information supplied (proportion of Commander's critical information requirements met).

7. Dimensional Parameters for C4ISR SoS

Kasunic [2001] introduces measures for connectivity and information flow that can be calculated from simple formulae. Although these measures do not directly provide assessments of the effectiveness and performance of a C4ISR SoS they may prove useful as measures of the efficacy of the information flow and connectivity for the network supporting the C4ISR SoS. As such they could be considered dimensional parameters underpinning measures of performance for C4ISR SoS. These measures are:

[4] Based on the 'intelligence cycle' [ADFP 101, 1994].

Connectivity Index, defined by:

$$C_i = \frac{k}{n(n-1)} \tag{1}$$

Where:

C_i = Connectivity Index
k = Number of connections
n = Number of nodes

Capacity, given by:

$$Q_{eff} = (Q_{\max} - Q_{oh})(t_f - t_p) \tag{2}$$

Where:

Q_{eff} = Effective system capacity (data rate)
$Q_{\max}$ = Maximum data rate
Q_{oh} = System overhead data rate
t_f = Time slot duration (unit transmission)
t_p = Unit propagation time

System Overload, defined by:

$$M_{OL} = n_t \sum_{y=1}^{n_r} (M_q)_y \tag{3}$$

Where:

M_{OL} = System message overload
n_t = Number of transmitting nodes
M_q = Messages in queue (to be transmitted by node)

Underutilization, given by:

$$Q_{uu} = M_{OL} \qquad \text{for } M_{OL} \le (Q_{eff} - Q) \tag{4a}$$

and

$$Q_{uu} = Q_{eff} - Q \qquad \text{for } M_{OL} > (Q_{eff} - Q) \tag{4b}$$

8. Use of C4ISR Architecture Framework

Because of the potential complexity of C4ISR SoS, and because they may be formed from different component systems to meet the evolving needs of different scenarios, a consistent means of describing C4ISR SoS was developed by the US DoD [C4ISR AWG, 1997]. The use of this C4ISR Architecture Framework (AF) enables comparisons to be made between ‘as is’ and ‘to be’ SoS and between alternative configurations. The C4ISR AF facilitates the description of the Information Exchange Requirements (IER) between the component systems or nodes of a C4ISR SoS. These IERs, and the attributes assigned to them, provide a way of developing a consistent description of information required within a SoS. Analysis of the IERs, which are specified for a particular instantiation, and use of a consistent description may help to provide light on which information requirements are critical.

Tools (such as Ptech Inc's FrameWork and Popkin's System Architect) have implemented the C4ISR AF. These tools provide a means of collating the IERs and, potentially, analyzing their use. They may thus provide, through case studies, a suitable test-bed for exploring the utility of, and developing further, the information metrics outlined here.

9. **Further Development**

Further development and testing of such measures in military trials or synthetic environment exercises is needed. What these proposed metrics currently do not include is the means for evaluating the SPED attributes that relates to how effectively the C4ISR information is used to achieve a military objective or desired outcome. Determining the military outcomes resulting from such information thus requires further development of concepts and identification of appropriate measures. In particular, metrics for the SPED attributes should assess the contribution of C4ISR information to how swiftly, precisely, extensively and decisively military operations are undertaken.

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