Critique, Explore, Compare, and Adapt (CECA): A new model for command decision making

David J. Bryant

Defence R&D Canada – Toronto

Technical Report
DRDC Toronto TR 2003-105
July 2003

Report Documentation Page			*Form Approved* *OMB No. 0704-0188*
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.			
1. REPORT DATE **JUL 2003**	2. REPORT TYPE		3. DATES COVERED **00-00-2003 to 00-00-2003**
4. TITLE AND SUBTITLE **Critique, Explore, Compare, and Adapt (CECA): A new model for command decision making**			5a. CONTRACT NUMBER
			5b. GRANT NUMBER
			5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)			5d. PROJECT NUMBER
			5e. TASK NUMBER
			5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Defence Research and Development Canada - Toronto,1133 Sheppard Avenue West,Toronto, Ontario M3K 2C9,**			8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSOR/MONITOR'S ACRONYM(S)
			11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**			
13. SUPPLEMENTARY NOTES			

14. ABSTRACT

This report argues that Observe-Orient-Decide-Act (OODA) Loop is outdated as a model of human cognition and proposes a new model based on theoretical advances in the psychological and behavioural sciences since the 1950s. The Critique-Explore-Compare-Adapt (CECA) Loop is explicitly based on the premise that goal-oriented mental models are central to human decision making as the means to represent and make sense of the world. The model assumes that operational planning establishes the initial conceptual model, which is a mental model of the plan. A situation model is created to represent the state of the battlespace at any given point in time. The four phases of the CECA Loop broadly correspond to the identification of information needs (Critique), active and passive data collection and situation updating (Explore), comparison of the current situation to the conceptual model (Compare), and adaptation to aspects of the battlespace that invalidate the conceptual model or block the path to goal completion (Adapt). The CECA Loop is intended to serve as a simple but widely applicable framework in which to think about decision making in the context of C2. Among the advantages of the CECA Loop over the OODA Loop are greater insight into the nature of perception and understanding, introduction of critical thinking elements, and exposition of the central role of planning and the mental representation of operational concepts in C2.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**63**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Author

David J. Bryant

Approved by

Ross Pigeau

Head, Command Effectiveness and Behaviour Section

Approved for release by

K.M. Sutton

Chair, Document Review and Library Committee

© Her Majesty the Queen as represented by the Minister of National Defence, 2003.

© Sa majesté la reine, représentée par le ministre de la Défense nationale, 2003.

Abstract

This report argues that Observe-Orient-Decide-Act (OODA) Loop is outdated as a model of human cognition and proposes a new model based on theoretical advances in the psychological and behavioural sciences since the 1950s. The Critique-Explore-Compare-Adapt (CECA) Loop is explicitly based on the premise that goal-oriented mental models are central to human decision making as the means to represent and make sense of the world. The model assumes that operational planning establishes the initial *conceptual model*, which is a mental model of the plan. A *situation model* is created to represent the state of the battlespace at any given point in time. The four phases of the CECA Loop broadly correspond to the identification of information needs (Critique), active and passive data collection and situation updating (Explore), comparison of the current situation to the conceptual model (Compare), and adaptation to aspects of the battlespace that invalidate the conceptual model or block the path to goal completion (Adapt). The CECA Loop is intended to serve as a simple but widely applicable framework in which to think about decision making in the context of C2. Among the advantages of the CECA Loop over the OODA Loop are greater insight into the nature of perception and understanding, introduction of critical thinking elements, and exposition of the central role of planning and the mental representation of operational concepts in C2.

Résumé

Nous affirmons dans le présent rapport que la boucle OODA (observer, orienter, décider, agir) est dépassée en tant que modèle de la cognition humain et nous proposons un nouveau modèle fondé sur les progrès théoriques accomplis depuis les années 50 dans les domaines de la psychologie et des sciences du comportement. La boucle CECA (critiquer, explorer, comparer, adapter) est explicitement fondée sur la prémisse selon laquelle les modèles mentaux orientés vers un but jouent un rôle prépondérant dans la prise de décision humaine, en tant que moyens de représenter le monde et de lui donner un sens. Le modèle tient pour acquis que la planification opérationnelle est à l'origine du *modèle conceptuel* initial, qui est un modèle mental du plan. On crée un *modèle de situation* pour représenter la situation de l'espace de combat à un moment donné. Les quatre étapes de la boucle CECA correspondent à la détermination des besoins en matière d'information (critiquer), à la collecte active et passive de données (explorer), à la comparaison de la situation actuelle avec le modèle conceptuel (comparer) et à l'adaptation aux aspects de l'espace de combat qui invalident le modèle conceptuel ou font obstacle à l'atteinte des buts (adapter). La boucle CECA propose une approche simple mais largement applicable de la prise décision dans le contexte du C2. Comparativement à la boucle OODA, la boucle CECA présente l'avantage de jeter une lumière nouvelle sur la nature de la perception et de la compréhension, d'introduire des éléments de la pensée critique et de faire ressortir l'influence déterminante de la planification et de la représentation mentale des concepts opérationnels sur le C2.

This page intentionally left blank.

Executive summary

The Observe-Orient-Decide-Act (OODA) Loop has been used as a model of basic decision making processes applicable to Command and Control (C2) since the mid-1950's. This model became popular because, in part, it seemed intuitively accurate but relatively simple and it also fit well with emerging concepts of control and information warfare in relation to the effects of time pressure and information gathering technology on C2 performance.

Despite its popularity, the OODA Loop is outdated as a model of human cognition. Significant theoretical advances in the psychological and behavioural sciences since the 1950s allow us the opportunity to develop a more accurate model that better explains not only how people make decisions but how the decision making process relates to the task environment. This report reviews four major themes that have been extremely influential in shaping how researchers understand cognition and which should be considered in formulating a model of decision making for C2:

1. **Cognition is goal directed:** Human beings are self-directing creatures who set objectives in the near- and far-term. Cognition must be viewed in terms of the purposes and goals people set for interacting with the physical and social world.

2. **Perception and understanding are constructive processes:** A range of cognitive theories have described perception and comprehension in terms of active, inference-making processes that attempt to "make sense" of the physical world based on sensory data. The constructivist perspective focuses on the ways people interpret what they observe and bring existing knowledge to bear in deciding how to achieve goals. These theories have shifted concern from information processing to the internal representation of objects and events in the external world and the ways pre-existing knowledge is actively used to interpret and understand those objects and events.

3. **Mental models are used to represent complex and dynamic situations and problems:** The defining characteristic of a mental model is that it maps elements of an external system (a problem, situation, or event) and the inter-relationships among those elements onto a conceptual structure. Mental models are situational and transient representations that continually adjust to represent the current state of the system or situation, playing a key role in decision making as the indicator of the current state of the environment.

4. **Critical thinking enhances decision making:** Critical thinking, broadly defined as the systematic questioning and evaluation of one's own reasoning strategies, is now known to be crucial to successful problem solving. Critical thinking motivates one to look for evidence that could potentially contradict what one believes and leads to evidence that potentially disconfirms one's mental model and necessitates adaptation of one's problem solving strategy.

These cognitive themes contribute to a strong C2 framework. This report describes some C2 concepts, including command concepts, common intent, and the "directed telescope" that are consistent with four cognitive themes discussed. Together, they suggest that the OODA Loop should be replaced by a model that explicitly refers to those themes.

The Critique-Explore-Compare-Adapt (CECA) Loop is proposed as just such a model. The CECA Loop is explicitly based on the premise that goal-oriented mental models are central to human decision making as the means to represent and make sense of the world. It also demonstrates the necessity of top-down guidance of perception. The CECA loop begins with planning that establishes the initial *conceptual model*, which is a mental model of the plan. Throughout an operation, the conceptual model will be a representation of how the operation is intended to proceed and, thus, is closely aligned with commander's intent. A *situation model* is also needed to represents the state of the battlespace at any given point in time. The "Critique" phase of the CECA Loop comprises the establishment of information needs by first questioning the conceptual model to identify critical aspects that, if invalidated, would render the plan for the operation untenable in some respect. In essence, by asking how the current conceptual model might be invalid with respect to the battlespace, the commander focuses on those aspects most important to determine how the plan needs to be adapted to changing conditions. When questions are formulated, specific information needs (i.e. data to be collected) are identified and used to direct information gathering.

The "Explore" phase of the CECA Loop comprises the active and passive collection of data from the battlespace. Active collection is guided by the information needs developed from above. Active data collection is directed to answering questions of the conceptual model's validity quickly and accurately. Passive collection is a filtering process in which events in the battlespace are monitored to determine whether any aspect of the battlespace not assessed actively should receive active attention. As data are collected, they are used to update the situation model to accurately represent the current state of battlespace.

In the "Compare" phase, the situation model is compared to the conceptual model to determine what, if any, aspects of the conceptual model are invalid (i.e. inconsistent with the current situation). It is then up to the decision maker to determine what to do in response to inconsistencies in the "Adapt" phase. In general, the decision maker can chose to ignore the inconsistencies if they are deemed of low consequence (i.e. inconsistencies with the conceptual model have little practical impact), alter the means to goals represented in the conceptual model to determine new actions required to reach the original goals, or alter the goals as well as actions represented in the conceptual model.

The CECA Loop, like the OODA Loop, is intended to serve as a framework in which to think about decision making in the context of C2. Although deliberately simplified to make it as widely applicable as possible, the model captures critical realities of human cognition and is geared to the iterative nature of military operations. The CECA Loop offers a number of advantages over the OODA Loop as a framework for understanding decision making in the C2 context. These advantages include greater insight into the nature of perception and understanding, the introduction of critical thinking elements, and exposition of the central role of planning and the mental representation of operational concepts in C2 performance.

Bryant, D. J. 2003. Critique, Explore, Compare, and Adapt (CECA): A new model for command decision making. DRDC Toronto TR 2003-105. Defence R&D Canada - Toronto.

Sommaire

Depuis le milieu des années 50, la boucle OODA (observer, orienter, décider, agir) a été utilisée comme modèle des processus fondamentaux de la prise de décision applicable au commandement et au contrôle (C2). La popularité de ce modèle est en partie imputable au fait qu'il semble intuitivement exact tout en étant relativement simple et que, de plus, il s'intègre bien aux concepts émergents de guerre de contrôle et de guerre de l'information, en ce qui concerne les effets des contraintes de temps et des techniques de collecte d'informations sur la performance du C2.

Malgré sa popularité, la boucle OODA est dépassée en tant que modèle de la cognition humaine. Depuis les années 50, des progrès théoriques importants ont été accomplis dans les domaines de la psychologie et des sciences du comportement; ils nous ont permis d'élaborer un modèle plus exact, qui explique mieux non seulement les modalités de la prise de décision, mais aussi les liens entre le processus décisionnel et le champ d'intervention organisationnelle. Dans le présent rapport, nous examinons quatre grands énoncés qui ont eu une influence extrêmement déterminante sur la compréhension de la cognition par les chercheurs et qui devraient être pris en considération au moment de l'élaboration d'un modèle de prise de décision pour le C2 :

5. **La cognition est orientée vers un but :** Les humains sont des créatures autodéterminées qui établissent des objectifs à court et à long terme. Il faut envisager la cognition en tenant compte des desseins et des buts que les gens établissent pour interagir avec le monde physique et social.

6. **La perception et la compréhension sont des processus constructifs :** Un éventail de théories cognitives ont décrit la perception et la compréhension sous l'angle de processus actifs de production d'inférences qui tentent de « donner un sens » au monde physique en se fondant sur des données sensorielles. La perspective constructiviste s'intéresse à la façon dont les gens interprètent leurs observations et extraient les connaissances existantes pour guider les décisions quant à la façon d'atteindre les buts. Ces théories ont entraîner un changement de perspective : l'accent ne porte plus sur le traitement de l'information, mais plutôt sur la représentation interne des objets et des événements du monde extérieur et sur les modalités d'utilisation active des connaissances préexistantes pour interpréter et comprendre ces objets et ces événements.

7. **Les modèles mentaux servent à représenter des situations et des problèmes complexes et dynamiques :** Un modèle mental a essentiellement pour objet de mettre en correspondance les éléments d'un système extérieur (un problème, une situation ou un événement) et les interrelations entre ces éléments au moyen d'une structure conceptuelle. Les modèles mentaux sont des représentations situationnelles et transitoires qui s'adaptent continuellement pour représenter l'état actuel du système ou de la situation, et ils jouent un rôle de premier plan dans la prise de décision en tant qu'indicateur de l'état actuel de l'environnement.

8. **La pensée critique améliore la prise de décision :** De façon générale, on entend par « pensée critique » la remise en question et l'évaluation systématiques de notre propre stratégie de raisonnement. On sait aujourd'hui qu'elle est essentielle à la résolution efficace des problèmes. La pensée critique nous incite à examiner des données qui pourraient éventuellement contredire nos croyances et apporter des preuves susceptibles d'ébranler notre modèle mental et de nous obliger à adapter notre stratégie de résolution de problèmes.

Ces énoncés sur la cognition servent de fondement à un solide cadre de C2. Le présent rapport décrit certains des concepts du C2, notamment les concepts de commandement, l'intention commune et le « télescope orienté », qui concordent avec les quatre énoncés sur la cognition analysés. Tous ces éléments semblent indiquer que la boucle OODA est dépassée et devrait être remplacée par un modèle explicitement fondé sur ces énoncés.

Ce modèle qui est proposé, c'est la boucle CECA (critiquer, explorer, comparer, adapter). Le modèle est explicitement fondé sur la prémisse selon laquelle les modèles mentaux orientés vers un but jouent un rôle prépondérant dans la prise de décision humaine, en tant que moyens de représenter le monde et de lui donner un sens. Il témoigne en outre de la nécessité d'une approche descendante de la perception. La boucle CECA débute par la planification, qui conduit à l'établissement du *modèle conceptuel* initial, lequel est un modèle mental du plan. Durant une opération, le modèle conceptuel illustrera la façon dont l'opération devrait se dérouler et, par conséquent, il concorde étroitement avec le dessein du commandant. Il faut en outre disposer d'un *modèle de situation* pour représenter la situation de l'espace de combat à un moment donné. L'étape « critiquer » de la boucle CECA comprend la détermination des besoins en matière d'information et, à cette fin, elle consiste dans un premier temps à remettre en question le modèle conceptuel pour relever les aspects critiques qui, s'ils étaient invalidés, auraient pour effet de rendre insoutenable le plan d'opération à certains égards. Essentiellement, en tentant de déterminer comment le modèle conceptuel actuel pourrait être invalide en fonction de l'espace de combat, le commandant fait ressortir les aspects qui permettront le mieux de définir les modalités d'adaptation du plan à l'évolution de la conjoncture. La formulation de questions permet de faire ressortir des besoins précis en matière d'information (c.-à-d. les données qu'il faut recueillir) et de s'en inspirer pour orienter la collecte d'informations.

L'étape « explorer » de la boucle CECA comprend la collecte active et passive d'informations sur l'espace de combat. La collecte active est guidée par les besoins en matière d'information établis à l'étape précédente. La collecte active des données vise à répondre rapidement et correctement aux questions concernant la validité du modèle conceptuel. La collecte passive est un processus de filtrage dans le cadre duquel on exerce une surveillance des événements dans l'espace de combat, afin de déterminer si un aspect donné de l'espace de combat ne fait pas l'objet d'une évaluation active alors qu'il le devrait. À mesure que les données sont recueillies, elles servent à mettre à jour le modèle de situation, de façon qu'il représente plus exactement la situation actuelle de l'espace de combat.

À l'étape « comparer », on compare le modèle de situation au modèle conceptuel afin de relever les éléments, s'il en est, du modèle conceptuel qui sont invalides (c.-à-d. qui ne concordent pas avec la situation actuelle). Il incombe alors au décideur de déterminer ce qu'il doit faire pour corriger ces discordances à l'étape « adapter ». En général, le décideur peut choisir d'ignorer les discordances s'il estime qu'elles n'ont guère de conséquences (ainsi, les discordances avec le modèle conceptuel ont peut de répercussions concrètes); il peut modifier les moyens retenus pour atteindre les buts dans le modèle conceptuel et proposer les nouvelles mesures à prendre pour atteindre les buts initiaux, ou encore modifier les buts de même que les mesures à prendre qui sont représentés dans le modèle conceptuel.

La boucle CECA, à l'instar de la boucle OODA, est une approche de la prise de décision dans le contexte du C2. Bien qu'on ait délibérément simplifié ce modèle de façon à en faciliter l'application, le modèle rend bien compte des aspects déterminants de la cognition humaine et est adapté au caractère itératif des opérations militaires. La boucle CECA est supérieure à maints égards à la boucle OODA en tant qu'approche facilitant la compréhension de la prise de décision dans le contexte du C2. Elle présente notamment l'avantage de jeter une lumière nouvelle sur la nature de la perception et de la compréhension, d'introduire des éléments de la pensée critique et de faire ressortir l'influence déterminante de la planification et de la représentation mentale des concepts opérationnels sur la performance du C2.

Bryant, D. J. 2003. Critique, Explore, Compare, and Adapt (CECA): A new model for command decision making. RDDC Toronto TR 2003-105. R & D pour la défense Canada - Toronto.

This page intentionally left blank.

Table of contents

Abstract i

Résumé i

Executive summary iii

Sommaire v

Table of contents ix

List of figures xi

List of tables xi

Acknowledgements xii

Introduction 1

Background 1

Purpose 2

The OODA Loop 3

History and Definition 3

The Popularity of the OODA Loop 5

Problems with the OODA Loop 6

Modern Perspectives on Human Decision Making 10

Goal-Directed Cognition 10

Constructivist Perception and Understanding 10

Mental Models in Decision Making 12

Critical Thinking 13

Concepts of Command Decision Making 14

Commander's Intent 14

Command Concepts 15

Common Intent 17

C2 as a Decision Making System 19
The Directed Telescope 21

The CECA Loop 23
A New Command Decision Making Loop 23
Walkthrough the CECA Loop 25
Premises of the CECA Loop 27
Putting the CECA Loop into Action 30
Advantages of the CECA Loop 34

Conclusion 36
Summary 36
Recommendations 37

References 39

List of symbols/abbreviations/acronyms/initialisms 44

Glossary 45

Distribution list 47

List of figures

Figure 1. The OODA Loop.. 4

Figure 2. Subset of Hierarchically Embedded OODA Loops for Own and Opponent Forces... 5

Figure 3. Intent Hierarchy (Adapted from Pigeau & McCann [54]) 18

Figure 4. Sharing Intent Leads to a Shared Conceptual Model 19

Figure 5. The Critique, Explore, Compare, and Adapt (CECA) Loop 24

Figure 6. The Conceptual Model Describes Intended States Over Time 28

Figure 7. Model-Guided Action and CECA Monitoring... 31

Figure 8. Balancing Risk with Respect to the Conceptual Model 33

List of tables

Table 1: Command Concepts 16

Acknowledgements

I would like to thank Joseph Baranski, Ross Pigeau, Sharon McFadden, David Smith, and Lt. Col. Ralph Giffin for their helpful discussions and advice.

Introduction

Background

It has been assumed for so long as to become axiomatic that the commander who can assess the battlefield, see opportunities, and mitigate threats more quickly and more accurately than the opponent will almost certainly prevail [1]. Whether a commander is able to accomplish this depends on the cognitive capabilities of the commander and his or her staff as much as the quality of sensors and intelligence gathering. Thus, development of doctrine and procedures have been guided by psychological research and theory, based on the view that understanding human cognition will facilitate support of planning and decision making, which will translate into faster and better decisions in the field [2]. This trend is illustrated in modern concepts of information warfare that target the enemy's decision making process as a centre of gravity [3]. Improving our understanding of human cognition is all the more important in light of the demands that new technology and asymmetric conflicts will place on commanders in terms of time pressure, complexity, and information overload [2].

Two models of human reasoning and decision making have been popular in military circles for linking cognitive theory to military doctrine. The first, and more recent, of these is the Cognitive Hierarchy, which was designed to describe the relationships between various kinds of data and understanding by commanders and staff [4]. The other, more dominant model is the Observe-Orient-Decide-Act or OODA Loop, which has served as a description of the continual decision making process of commanders for roughly 50 years. Also called the Boyd Loop in honour of James Boyd, the man who formulated the theory, the OODA Loop is often referred to as a cornerstone of information- or command-centric warfare [1]. By conceiving of friendly and enemy forces in terms of competing cycles of decision processes at various levels of command, military theorists have been able to identify ways of speeding up one's own decision making while interfering with and slowing down the enemy's. The key assumption is that completing one's own decision cycle faster than one's opponent will yield ever-increasing advantages in Command and Control (C2) effectiveness, which will, in turn, yield greater battle success [1].

To obtain positive combat effects from good decision making, it is necessary to have the best possible theory of cognition underlying one's concept of C2. A good cognitive theory is one that is most descriptive of how people actually think under various conditions and highly predictive of how people will think and act in any specific situation. Such a theory conveys a number of advantages to C2. First, it will inform military analysts and planners where support for command decision making is required and what kinds of support will be effective [5]. Second, a good cognitive theory is needed to design training, doctrine, and procedures to be consistent with natural human reasoning and enhance its strengths and mitigate its weaknesses [2] [3]. Finally, by understanding how the mind works, one can decide what organizations, processes, and technology will most effectively aid decision makers deal with pressures of limited time and information overload. A poor cognitive theory, however, will produce negative effects on C2 when used as the basis for doctrinal thinking. For example, commanders in the past have been instructed to perform complex analytic strategies in highly pressured contexts in which humans simply do not have the capability to perform [6]. Over the last 10 years or more, military analysts have recognized the value of intuitive or naturalistic decision making theories and their role in guiding doctrine [7].

Purpose

The aim of this report is to propose a better cognitive model to replace the popular OODA Loop. In reviewing the history and application of the OODA Loop, it will be demonstrated that the OODA Loop does not conform to what is currently known about human reasoning and decision making and, in fact, masks several critical aspects of decision making that need to be better supported to enhance C2. A brief review of modern perspectives on human decision making will illustrate these problems with the OODA Loop and serve as the bases for a new dynamic model that will emphasize the roles of mental representation and active questioning in developing better situational awareness and making better judgments. The Critique-Explore-Compare-Adapt (CECA) model maintains the simplicity of the OODA Loop so that it can serve as a readily understandable and usable model of cognition but also takes into account modern cognitive concepts. It is argued in this report that the CECA model is not only more consistent with modern perspectives on cognition but is more compatible with modern perspectives on C2 and actual practices of effective military commanders.

The OODA Loop

History and Definition

The OODA Loop was first proposed by U.S. Air Force Colonel John Boyd in the mid-1950s as a means to describe basic decision making processes. In conducting a study of air-to-air combat during the Korean War [1] [8] [9], Boyd noticed that American F-86 Sabre pilots enjoyed great success against their Communist opponents despite the technical superiority of the MiG-15. Boyd attributed this superiority to the better cockpit visibility and fully hydraulic flight control system of the F-86 [8]. It was not the technical characteristics of the aircraft themselves, however, that led to success. Rather, Boyd argued that American pilots, with a visibility advantage, were able to decide and act faster than their opponents. The American pilots were able to assess a changing situation quickly and manoeuvre in response. Through a series of such manoeuvres and counter-manoeuvres, American pilots generally were able to get into a firing position before their opponent could react.

Boyd took from his study the lesson that faster detection of the enemy's actions, assessment of their implications, and decision on how to respond could convey a significant combat advantage. This idea resonated with military thinkers around the world and the notion of the OODA Loop entered doctrine in the United States and other NATO countries without a great deal of critical examination [8]. Boyd's theory that conflict can be viewed in terms of a contest between time-competitive observation-orientation-decision-action cycles provided a powerful means for people to think about C2 [1]. It must be noted, however, that Boyd himself made no effort to demonstrate the applicability of the OODA Loop to C2 contexts beyond air-to-air combat [8].

The OODA Loop model proposes four basic steps in decision making, which are performed in a cyclical sequence (see Figure 1). Thus, decision making is not a discrete act but rather a continuous activity composed of a few basic processes: Observe, Orient, Decide, and Act [1] [9]. In the *Observe* process, information about the current situation is gathered by any and all means available. Information pertaining to all relevant aspects of the battlespace, including enemy and own forces, is gained both by actively searching the environment and passively receiving sensor inputs. The *Orient* process involves the analysis of this information. The C2 staff makes estimates and judgments concerning the proper interpretation of information and create a coherent picture of the situation and its implications. The next stage is the *Decide* process, in which the C2 staff and commander consider the orientation and determine appropriate actions to achieve goals and mitigate risks. Finally, in the *Act* phase, the decision is implemented. A key aspect of the Act process is the continued monitoring of the situation so that more information is gathered and the cycle of processes continues.

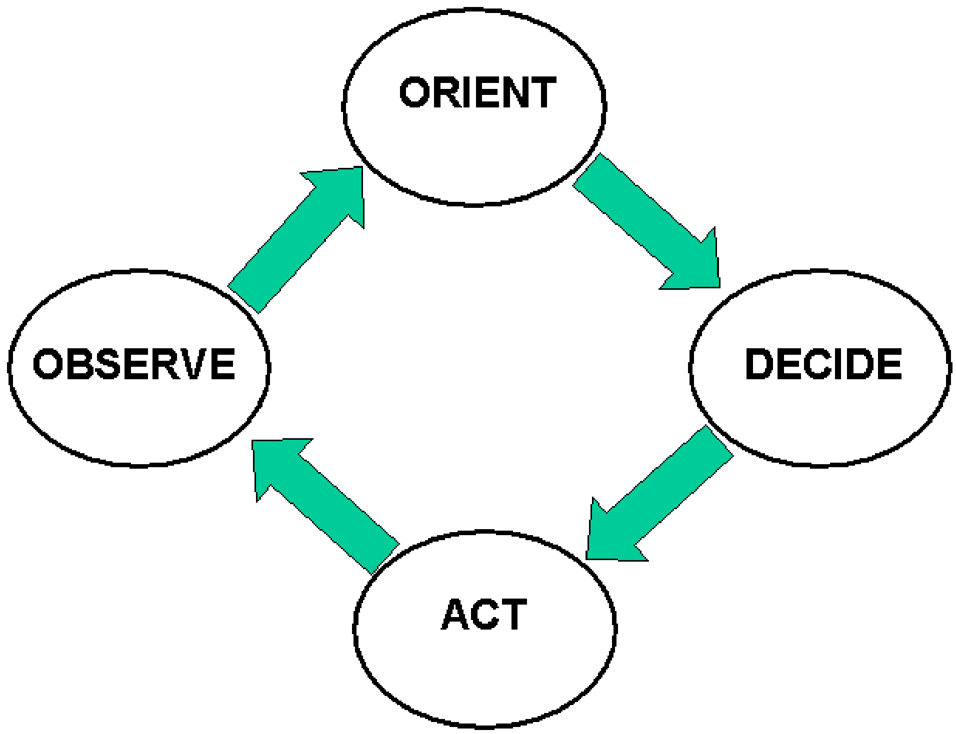

Figure 1. *The OODA Loop*

Figure 1 shows the OODA Loop as it is typically illustrated, as a simple loop with four broad processes embedded within it. Thus, the OODA Loop model is most often used as a straightforward tool for discussing decision making by one's self and one's enemy. The model provides a way to identify and target critical aspects of decision making, which is consistent with the concept of control warfare that victory can be achieved by attacking the enemy's decision making processes [8].

The OODA Loop has also been viewed as an organizational model (e.g. [9]). Because the stages of the OODA Loop are intended to describe decision making processes in general, across contexts, it is assumed that each level within a command hierarchy performs its own OODA Loop. Figure 2 illustrates this idea; decision making at a given level of command is represented by a loop, with the decision making of lower levels of command contained within it. Likewise, the decision loop of any given level of command is subsumed within the decision loop of the next higher level in the command hierarchy. These multiple decision loops are assumed to proceed simultaneously and interactively, such that performing the decision cycle at a given level depends on the performance of decision cycles below and, in turn, constrains the performance of the decision cycle above [9].

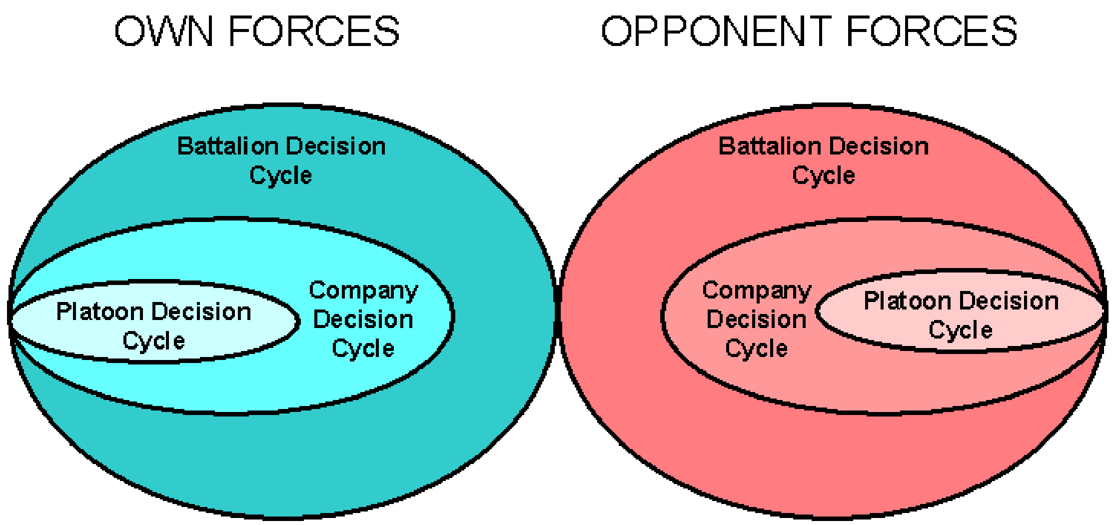

Figure 2. *Subset of Hierarchically Embedded OODA Loops for Own and Opponent Forces*

Figure 2 also illustrates the competitive aspect of the OODA Loop model. Just as one's own forces perform decision cycles within the command hierarchy, the opponent is assumed to perform the same decision cycles. In this context, the own forces achieve C2 superiority by performing the decision cycles faster than the opponent at every level of command [8]. With shorter decision cycles, the own forces can select an action and implement it before the opponent is able to adequately observe, orient, and decide, conveying the initiative to the own forces. Moreover, speed in decision cycles at lower levels of command will convey advantages to higher levels of command that depend on information moving up the command hierarchy. Thus, for example, if a platoon can perform its decision cycle faster than the opponent and pass information to the company level, the company level will be able to speed its observation and orientation relative to the opponent.

The Popularity of the OODA Loop

Plehn [8] notes that the OODA Loop was accepted in doctrine without very much critical examination. This may be due to the model's straightforwardness as a tool for thinking about decision making in the context of C2. There are, however, a number of concrete advantages to the OODA Loop model that likely also factored into its popularity.

First, the OODA Loop tends to strike people as an intuitively accurate but relatively simple model that captures important aspects of the decision making process without an excessive burden of detail. In particular, the OODA Loop highlights the distinction between information gathering activities (Observe and Orient) and analysis and implementation (Decide and Act). Achieving the appropriate balance between these broad activities is certainly an important consideration in creating an effective C2 system. Furthermore, the OODA Loop captures the continuous nature of C2 in which no action is ever final; as one acts, one changes the battlespace and necessitates further data gathering and decision making.

The OODA Loop also provides a framework in which to consider the effects of time compression and information gathering technology. Boyd developed his model at a time when warfare had changed dramatically in terms of speed and the importance of information from traditional views of warfare. The early successes of German Army in World War II had shown the potential of rapid manoeuvre warfare and suggested that commanders would never again be afforded sufficient time or information to deliberately and analytically assess their options. In this context, the OODA Loop is attractive as a concept of the flexible, continually adjusting C2 system [1].

Finally, the OODA Loop fit well with emerging concepts of control and information warfare [4] [7]. Just as the OODA Loop is intended to describe one's own decision making, it is used as a model of the enemy's decision cycle. Thus, the OODA Loop was used, in part, as a basis for identifying key aspects of the enemy's decision cycle and C2 system to target as part of control warfare.

Problems with the OODA Loop

Despite its popularity, the OODA Loop is deeply flawed as a model of human decision making. The next section briefly reviews significant theoretical advances in the psychological and behavioural sciences that have occurred since Boyd formulated his model in the 1950s. These advances make clear that the OODA Loop is not consistent with what we now know about decision making and, in fact, obscures several critical aspects of human cognition that should be incorporated in any model used to create C2 doctrine or procedures.

One important flaw of the OODA Loop is that, although it identifies broad aspects of decision making, the model provides no indication of *how* one should go about performing these aspects. That is, the OODA loop concept offers no insight to how one should observe the battlespace, how one should orient to relevant information, etc. It is possible to do much better in specifying a dynamic decision making model while still retaining a desirable degree of simplicity. The deceptive intuitiveness of the OODA Loop obscures the underlying processes that people use to effectively seek information and use that information to generate and select from courses of action.

Possibly worse, the OODA loop does not specify *why* each of its four steps should be performed. That is, the model provides no specification of what functions Observe, Orient, Decide, and Act serve with respect to the actual battlespace environment. Consequently, the OODA loop does not capture the essential goal-directedness of command decision making. This makes the OODA loop *reactive* rather than proactive as it suggests that decision making occurs only in reaction to environmental events. This perspective has been useful in exploring the role of situation awareness in many decision tasks but is too vague to help one understand the interplay of planning and implementation in hierarchical C2 organizations (e.g., [8]). One consequence of this is that the OODA Loop provides no guidance on how to define information needs from the commander's perspective or procedures for managing information [10]. Without understanding how people use information in decision making, it is difficult to determine the best ways to search the vast amount of information made available by modern sensor technologies.

The OODA loop is largely silent about how observation and decision making are actually done, but Giffin [11] has argued that the model is implicitly based on the philosophical school reasoning known as inductivism. This theory has its roots in the philosophy of science but the relevant aspect here is the idea that observation is a process of unbiased reception of information, that "facts" will manifest themselves in what one observes. In its strongest form, the theory of inductivism has important flaws (see [12]). Without delving too deeply into the long-standing debate concerning the validity of inductivism, this theory implies that observation should be "unbiased," without pre-conceived ideas or theories intruding on the process of gathering information from the environment. Such a concept of unbiased observation, however, ignores the critical importance of "top-down" cognitive processes in making sense of our perceptions [13].[1] People need existing theories about how the world is structured in order to interpret events in meaningful ways. Given the infinite number of potential interpretations that can be given to any observed phenomenon, "unbiased" observation would yield only a mass of so-called "facts," none of which could be discounted without an infinite number of further observations. This problem is best illustrated through a story:[2]

> *Four philosophers were travelling by train to Glasgow when one looked out the window and saw a white sheep grazing in a field. Priding himself on his skill of induction, the first philosopher comment to his friends that based on his observation, one could conclude that the sheep of Scotland are white. The second philosopher, however, had studied a little harder and knew the dangers of extrapolating too much from a single observation. "No, my friend," he said, "we can only conclude that at least one sheep in Scotland is white because we have to admit the possibility that other, differently coloured sheep may exist elsewhere in Scotland." The second philosopher was pleased with himself but the third philosopher, being somewhat of a wag, decided to take some of the steam out of his friend. "Actually," the third philosopher stated, "because we only saw the sheep from one vantage point, we can only conclude that there is at least one sheep in Scotland that is white on one side! We must admit the possibility that the very sheep we saw could have been a different colour on the opposite side, which we were not able to see." The second philosopher was forced to concur and congratulate his friend on his great insight. The fourth philosopher, however, was the wisest of them all. "Actually," the fourth philosopher said, " we can only conclude that we experienced a particular perception. For you see, we must admit the possibility of any number of things that could have led to our perception. Perhaps a thousand predominantly white moths happened to fly in a cluster just as we looked that way and gave the impression of a sheep. Or, perhaps light reflecting off shiny rocks in the area all converged in such a way that, when refracted by layers of warm and cold air, we experienced our*

[1] Gibson's [14] theory of direct perception provides a contrasting view of perception that focuses on the invariant structures within the physical world that constrain perception without the need of top-down processing.

[2] The story presented here is my best recreation from memory of a story I encountered early in my education. Unfortunately, I have been unable to locate the original source to give proper credit where it is due.

> *perception even though there was not any physical object there at all! Gentlemen, I submit to you that we can know nothing of the sheep of Scotland, nor anything else, on the basis of our observation!" The first philosopher objected, "But your explanations are preposterous! We all know that sheep exist in Scotland, that sheep are generally white or black, and that the probability of moths accumulating in such a way as to look like a sheep or light bending at just the right angles is astronomically low!" The fourth philosopher smiled and replied, "Yes gentlemen, but are you not familiar with induction? We must be unbiased, and whether an interpretation of our perception seems unlikely, we must allow the facts to manifest themselves."*

Of course, anyone seeing a white sheep from one side would assume that what they saw was indeed a white sheep with wool of a single colour. This story illustrates the problem of achieving truly unbiased observation, that "facts" cannot manifest themselves from just observation because observation is inherently subjective. The story also illustrates how perception is viewed as an inferential process that interprets sensory data to determine what physical objects and events gave rise to those sensations.[3] To understand the world – far from a lack of bias – people *require* pre-existing concepts to guide their interpretation of what they perceive. Such pre-existing concepts not only distinguish the most plausible interpretation of an observation but also guide us as to what portion of all the available sensory data is relevant and will direct our attention to important objects and events in the environment.[4]

The OODA Loop, with its undefined Observe and Orient processes does not even hint at this necessary dependence of perception on pre-existing knowledge and concepts. This is the greatest failure of the OODA Loop as a model of human decision making, a failure that has led to a mistaken emphasis on information gathering as a "bottom-up" process that creates understanding of the battlespace solely from gathered data [11]. This, in turn, has been partly responsible for the over-emphasis on technology as a solution to C2 problems (see [18], pp. 73-74). When decision making is viewed primarily as a problem of obtaining as much information as possible, it is easy to conceive of automation as a solution. It should become clear in subsequent sections, however, why simply expanding the capacity to collect more, and more precisely resolved, data does not itself aid human decision making.

Although the OODA loop seems to view perception in simple bottom-up terms, John Boyd probably did not intend his model to exclude top-down processes. Colonel Boyd created his model in the context of jet air warfare, where there were relatively few entities involved at any given time, and the pilots performed highly structured tasks. In the air-to-air combat environment of the Korean War, enemy units were clear and the foremost "decisions" for American pilots were to assess the presence and relative bearing of enemy aircraft and to determine whether firing position had been achieved. This context allowed the model-driven, top-down nature of perception and DM to be hidden within implied assumptions. Thus, when

---

[3] The writings of Hermann von Helmholtz [15] largely introduced the theory of perception as an inferential process.

[4] The question of where all of our pre-existing concepts come from is well beyond the scope of this paper. Both evolutionary[16] and developmental processes [17] must be critical, as well as individual "bootstrapping" by elaborating and expanding concepts as new information is gathered and integrated with existing knowledge.

Boyd formulated the “Observe” stage, it was implicitly based on the definitions of what was to be observed, what physical characteristics were important to the information gathering process, and what data would provide evidence of the presence and location of enemy aircraft.

We generally take perception for granted because it seems so automatic; we are not aware of the complex top-down cognition involved in directing our attention and interpretation of perceptual data [19]. But when we consider information gathering and decision making in complex, socio-technological systems, problems are not so structured. In particular, command of military forces is likely to present highly unstructured problems in which a commander must formulate concrete objectives. It is not always clear what aspects of the environment (especially enemy forces) are relevant or useful in assessing the situation at a given moment of time. A commander must think about what he/she wants to do, what resources are available, what the enemy might do, and what data *should* be collected to assess all this. So, where OODA loop leaves these issues implicit in the “Observe” and “Orient” stages, it is vital when working in complex C2 environments to make these issues explicit. That is, we must specify the role of the operational plan or the commander’s intent in defining the “rules of the game,” that indicate the basic sets of factors that govern how one will search the environment and use data to assess the status of one’s own goals and potential actions of the enemy.

Modern Perspectives on Human Decision Making

A great deal of progress has been made in the cognitive and behavioural sciences since Boyd formulated the OODA Loop in the mid-1950s. At that time the mechanistic information processing view was becoming prominent. With the advent of computers, it seemed natural to view cognition as a series of processing steps in which information went into the system, computations were performed, and an appropriate output was produced. In the intervening 50 years, however, cognitive scientists have begun to view human cognition in a much more ecological context – a context that places greater emphasis on the adaptive interaction of the mind with the environment as well as internal representations of the world [20].

A complete review of all the advances in cognitive theory is very much beyond the scope of this report. Instead, this section will discuss four perspectives that have been extremely influential in shaping how researchers understand cognition and which should be considered in formulating a model of decision making for C2.

Goal-Directed Cognition

Human beings are independent, self-directing creatures. We set objectives in the near-term, such as obtaining food, making a trip, or identifying immediate tactical goals in performing a mission, as well as the long-term, such as determining a career, or determining strategic aims for national defence. The information processing perspective that underlies the OODA Loop generally presumes that people are largely passive reactors to external events as it focuses on gathering information about the world and deciding what to do in response to that information. During the mid-1970s, however, research on higher-level cognition led to a change in this perspective to one in which people are seen as active and curious, purposively interacting with the physical and social world [21]. Although, the Decide and Act steps of the OODA Loop affect the world, Boyd did not include an explicit role for plans, intentions, or goals. These, however, are critical to decision making, as illustrated by studies that have shown that success in solving complex problems or controlling complex systems depends on clearly identifying goals and subgoals and effectively planning means to achieve them (e.g., [22] [23]).

Constructivist Perception and Understanding

Although the OODA Loop model may suggest a purely mechanistic, information-driven view of cognition, the dominant view of perception and understanding now is that these are *constructive* processes [24]. The term "constructivism" has several meanings within the field of psychology, from Piagetian theories of human development (see e.g., [25]) to perspectives on psychosocial processes (e.g., [26]). In this report, I take the term to refer to the range of cognitive theories that describe perception and comprehension in terms of active, inference-making processes (e.g., [19] [27]). In this sense, to call perception "constructivist" is to argue that we perceive the world through the interaction of bottom-up and top-down processes, which work to select, modify, and interpret sensory data to create a coherent and meaningful understanding of the physical world. This view of perception as active "sense-making" owes a great deal to the work of Irving Rock, whose general framework describes perception as a problem solving process. Rock [19] argued that the cognitive system works to determine what situation in the external world could have produced the given pattern of sensory stimulation. In this sense, we see the analogy of C2 to perception [18]; just as the commander must try to create a picture of the battlespace based on finite sensor data, so too every human creates an internal model of the external world based on his or her own finite sensory data.

The constructivist perspective focuses on the ways people interpret what they observe and bring existing knowledge to bear in deciding how to achieve goals [21]. In this perspective, sensory data are evaluated with respect to pre-existing concepts and knowledge of the world (physical and social) and integrated with these concepts and knowledge to create an internal representation, or mental model, of the state of the external world. This constructive process is evidenced by perceptual illusions in which the mind misinterprets perceptual data that are more consistent with a common, expected physical reality than the actual, contrived situation employed to demonstrate the illusion (see Shepard [28] for an engaging exploration of visual illusions).

As studies of higher-level cognition became increasingly popular, cognitive scientists came to see perception and comprehension as "coherence-seeking" processes in which people spontaneously coordinate different sensory data and pieces of information to build a coherent system of knowledge that can explain the world [21]. The central concern shifted from information processing to mental representation. A mental representation is the internal mapping of information to external objects and events in the world. There are, of course, different kinds of mental representations for different contexts and purposes, from knowledge and beliefs that comprise more or less stable representations of regularities in the world to more transient and dynamic mental models that represent an ongoing situation [29] [30]. In between are concepts, mental rules, theories, and procedural knowledge, all of which serve as bases for understanding how the world works, how the current situation relates to the world and one's previous experience, and how one can interact with the world to effect changes [21].

In contrast to the early information processing view, top-down processing plays as significant a role in perception and comprehension as bottom-up, sensory processes (see, for example, Rock's [19] excellent discussion of inferential processes in perception). That is, our mental representations guide perception and information gathering activities – essentially telling us how to observe the world, discern what is and is not relevant, and relate observed phenomena to our goals. Knowledge is used to direct sensory systems, identifying the kinds of objects and events that are likely to be of interest, setting thresholds on the various kinds of phenomena that might attract attention, and so forth. Knowledge is also used to assemble gathered sensory data into a coherent and plausible *interpretation* of the state of the world around us [19]. This is a key premise of the constructivist perspective, that our experience and understanding of the world is not an absolute truth; it is, instead, our best attempt to explain the data our senses have gathered and provide a mental model that can be used to plan actions to be taken in that world. We may not be aware of the hypothetical nature of perceptual experience, but that is only because our cognitive systems are the evolutionary legacy of millions of years of trial and error that have produced highly reliable systems for interacting with the physical world. When we step into an unnatural world, such as that of modern warfare, however, it is critical to bear in mind that data are simply building blocks and the value of the end product, our understanding, depends also on the concepts and knowledge brought to bear in interpreting the data.

In the constructivist perspective, the terms data and information take on clearly different meanings. Data result from sensory processes and are the most immediate transductions of physical energies into a representational form. Information results from the interpretation of sensory data based on concepts and knowledge and can be considered to be representations of limited aspects of the external world that are consistent with our general knowledge. Knowledge is integrated information, making up a complex network of information that is organized to provide a coherent representation of everything we know about the world. Understanding, in the cognitive sense, arises from the integration of information with existing knowledge, so that current observations can be related to an organized knowledge representation [31].

Mental Models in Decision Making

The constructivist perspective encompasses more than just information gathering and understanding; it implies the intricate inter-relation of all aspects of cognition. Decision making, as viewed from the constructivist perspective, entails identifying the kinds of information needed to address the problem, gathering that information and interpreting it, and creating a mental model to be used in mentally determining decision options and evaluating potential outcomes [32]. Thus, concepts of mental representation are critical to understanding the overall decision making process. Among the most important class of representations studied is the mental model.

The concept of the mental model was developed as a means to describe complex and rich mental representations used in reasoning (e.g., [29]). The defining characteristic of a mental model is that it maps elements of an external system (a problem, situation, or event) and the inter-relationships among those elements onto a conceptual structure [33] [34]. Thus, a mental model contains elements that correspond to the objects and properties making up the external system represented in an organized format so that the model elements are inter-related in the same fashion as the external elements. A mental model is certainly less detailed than reality, may vary in the form of representation, and often emphasizes certain elements and relationships over others but, nonetheless, serves as an internal simulation of external systems.

Mental models are situational representations – that is, they take their structure from the structure of the system modeled. Consequently, mental models of different systems will exhibit different characteristics depending on the complexity of the system and the demands of the individual’s task (which will make some elements more relevant than others) (Moray, 1999). In addition, mental models are transient and dynamic representations that continually adjust to represent the current state of the system or situation [21]. If problem solving is viewed as the exercise of control over a complex system, the mental model plays a key role as the indicator of the current state of the system, the “here and now” [22]. This situation representation can be used to evaluate the current state in relation to desired goal states and serve as a working model for simulating the effects of potential actions. But the mental model must change as events and the effects of actions alter the external system.

The use of mental models in problem solving and the exercise of C2 has been well documented [35] [36] [37]. An accurate mental model helps individuals see how events are unfolding in relation to the operational plan and validates assumptions in the plan [37]. Comparing the plan against the current situation allows the individual to see when and how the plan is succeeding as well as where problems occur.

Mental models can be shared among individuals working together on a common problem. For teams to work effectively toward a clear set of goals, team members must share the same perceptions of goals and contingencies [38] [39] [40] [41]. A common premise of research examining team functioning is that having a shared mental model aids a team by providing common goals, defining working relationships/roles, facilitating communication and coordination, and reducing redundancy in planning activities [34] [42] [43] [44]. Thus, shared mental models are thought to keep team members "on the same page," and help them work in ways that support each other and the team as a whole.

Critical Thinking

Critical thinking, broadly defined as the systematic questioning and evaluation of one's own reasoning strategies, is now known to be crucial to successful problem solving. This is recognized not just in the psychological literature [45] but also studies of military decision making and development of military training procedures (e.g., [46] [47] [48]).

Critical thinking is akin to hypothesis testing in science. Science proceeds through the development of theories about phenomena. A theory serves as the best causal explanation for some phenomena until evidence is found that contradicts predictions of that theory. When this happens, the theory must be revised or replaced to produce a better explanation. Through continual testing and revision, science progresses towards better explanations with the understanding that perfect explanatory power is unachievable. In a similar sense, our mental models act as the best explanatory theory available when solving a problem (e.g., [49]). Critical thinking performs the same role as hypothesis testing by calling into question elements of the mental model. As a decision making strategy, critical thinking motivates one to look for evidence that could potentially contradict what one believes in one's mental model of the problem. This leads to evidence that potentially disconfirms the mental model and necessitates some revision or re-thinking of the problem or one's strategy for solving it.

Insufficient critical thinking has been identified as one common maladaptive aspect of decision making (e.g., [22]). When one fails to examine one's knowledge and the accuracy of one's predictions concerning how events will unfold, one tends to remain fixed on the initial decision or plan. This can be disastrous as it is unlikely, except for the simplest of problems, that one is able to plan a successful solution in full ahead of time. Critical thinking promotes adaptivity and helps one detect failures in one's problem solving strategy. This in turn improves one's ability to cope with complexity and uncertainty [3]. Critical thinking is associated with good metacognitive capabilities, which comprise strategies for assessing one's own knowledge, identifying critical aspects of one's mental model, and seeking information to test the critical assumptions and predictions derived from the mental model [50].

Concepts of Command Decision Making

Numerous writers have noted the need for a strong organizational framework in C2 (e.g., [10] [18]). That framework should be consistent with what we know of human cognition and play to the strengths of natural decision making. If commanders have to struggle with a non-intuitive organization, the entire C2 structure is undermined. This is especially true as the complexity of the battlespace, in terms of information and pace of events, increases [10]. The C2 structure should make effective decision making as easy as possible, which is accomplished by designing the C2 organization around an appropriate cognitive model. As shown in the previous section, the OODA Loop is not an appropriate model given the progress that has been made in the cognitive sciences.

There has been a movement in military thinking toward command-by-influence C2 organization, which designates decision making to the lowest unit possible rather than exert strict control from upper levels of command [51]. This is done by disseminating the operational intent and outline, which commanders in the field use as guidance in interpreting their mission in the context of the evolving battlespace situation. Command-by-influence is justified on grounds of economy of information and superior flexibility of forces [52] but is also consistent with the major themes of cognitive theory laid out in the previous section. This organization emphasizes *goal-directed* control, in which units are provided with objectives and a general outline of how to achieve them, but left free to determine an appropriate course of action based on their interaction with the environment. Command-by-influence implicitly acknowledges that humans understand and think in terms of *mental models* that can be shared. What remains to be done is clearly specify the roles of *constructive knowledge acquisition* (data gathering and processing) and *critical thinking* in C2.

This section will describe some work already done on linking modern elements of cognitive theory to C2 organization.

Commander's Intent

Although the OODA Loop makes no reference to goals or plans, CF doctrine clearly recognizes the importance of a comprehensive plan to guide actions and decision making in the field. Command intent is the broad concept of the purpose, general methods, and constraints pertaining to a particular operation, which guides the development of specific products of the planning process, such as a commander's statement of intent. The statement of commander's intent includes the purpose, method (or tasks), and desired end state, of the planned mission or operation. Whatever the prescribed format, the intent statement is expected to precede any detailed instructions. There is debate about the appropriateness of including 'method' within a statement of intent because a lengthy method section may prove counterproductive to the aim of providing a goal-related model that can help subordinates cope with unforeseen circumstances [44]. An alternative to including an outline method may be some explicit statement of the constraints on actions or approaches that subordinates may take in the event that the plan fails.

Command intent can be seen as both an event and a process (see [53]). As an “event” it is seen as an explicit mission-related statement made in a certain format at a certain point in a mission sequence. There is an emphasis on the need for brevity and clarity so that the statement is memorable and easily recalled under difficult conditions. Subordinate commanders use it as a point of reference for developing their own statements of intent, for planning their own missions, and during execution of these missions, especially when any original plan falters. Intent statements are hierarchical and must be directly related to the intent statements of superior, subordinate and lateral commanders. As a “process,” command intent is an on-going process of creating shared implicit intent through activities both before and after the formal statement of intent for a specific mission. Long-term preparation of personnel is seen as crucial to success of any specific mission, especially in terms of building common understanding of doctrine, procedures, and capabilities among members of the military organization.

Notwithstanding such long-term preparation, success of a mission must also be based on mutual comprehension among all participants of the explicit statement of intent. This is achieved through formal and informal activities such as iterative feedback (e.g., back briefings) and rehearsal. The preparation of the intent statement, the specific plan based upon it, and the implementation of contingencies in the face of unforeseen circumstances, are seen as parts of a collaborative process among commanders at all levels. Intent statements may also be used to filter or fuse information appropriately for superior or subordinate commanders during an operation.

Command Concepts

Members of the military commonly refer to the notion of a commander's "vision" for a military operation, which encompasses the expectations of possible and desirable outcomes [39] [44]. The commander’s vision lays out a plan for an operation with contingencies and indicators used to monitor whether the operation proceeds as anticipated. Consistent with this idea, Builder et al. [39] have defined a command concept as "a vision of a prospective military operation that informs the making of command decisions during that operation." Perhaps a better term than vision for this concept is *conceptual model*, a term that captures the complexity and comprehensiveness of the mental representation of the operation. Lying at the heart of effective C2, the conceptual model can be thought of as a mental model of the operation that can be shared among individuals. They have further identified as the two key elements of effective C2 the quality of commanders' vision, or conceptual model, of how an operation will unfold and the degree to which that vision is shared among individuals and units who will contribute to accomplishing specified goals. Thus, effective C2 relies on a concept of impending operations that guides subsequent command decisions by both the overall commander and all subordinate commanders as they prepare, promulgate, and implement their own concept of operations within their limit of responsibility. The overall commander and staff develop the overall conceptual model of an operation, which describes the plan for achieving operation objectives. The conceptual model lays out the premises and goals of the operation and guides all subordinate commanders. Builder et al. suggest a set of command concepts (see Table 1) that should be included in a conceptual model of an operation. Included in these command concepts are specifications of data or observations that will signal flaws or problems in the concept of operation as well as describe some contingency plans. These are critical for monitoring the validity of the plan and adaptation to unforeseen events.

Table 1: Command Concepts

	Conceptual Element
1	Time scales that reveal adequate preparation and readiness, not just of the concept but of the armed forces tasked with carrying out that concept.
2	Awareness of the key physical, geographical, and meteorological features of the battle space - situational awareness - that will enable the concept to be realized.
3	A structuring of forces consistent with the battle tasks to be accomplished.
4	Congruence of the concept with the means for conducting the battle.
5	What is to be accomplished, from the highest to the lowest levels of command.
6	Intelligence on what the enemy is expected to do, including the confirming and refuting signs to be looked for throughout the coming engagement.
7	What the enemy is trying to accomplish, not just his capabilities and dispositions.
8	What the concept-originating commander and his forces should be able to do and how to do it, with all of the problems and opportunities - not just the required deployments, logistics, and schedules, but the nature of the clashes and what to expect in the confusion of battle.
9	Indicators of the failure of, or flaws in, the command concept and ways of identifying and communicating information that could change or cancel the concept.
10	A contingency plan in the event of failure of the concept and the resulting operation.

Adapted from Builder et al. [39].

The sharing of the concept of the operation is as critical as its formulation. By reference to a shared concept, subordinate commanders can respond to unfolding events in a manner consistent with the overall commander's vision. Sharing the concept also enables subordinate commanders to select and channel upward only information that relates to the continuing effectiveness of the concept.

Builder et al. [39] have supported their idea with analyses of historical military operations. They have found that the successful command concept is a "…statement of the commander's intent that should have been, under the doctrine, training, and common knowledge of the time, clearly sufficient for subordinate commanders to successfully execute the responsibilities they were actually called on to fulfill during battle, without exchanging additional information with their superior commander." Builder et al. summarize this definition as the answer to the question, "*What would the commander have had to tell his subordinates before the battle in order to have made their subsequent actions conform to his concept?"* Thus, the core of the command concept is derived from considerations of the information needed by the commander to evaluate the concept against the unfolding operation. Indeed, consideration of information needs guides the description of the concept to subordinates and the data processing strategies adopted by subordinates, who draw from the concept guidance on what information to seek and pass upward. Builder et al view the ideal C2 system as transmitting only information that will help commanders at any given level identify flaws in the conceptual model of the operation/mission.

Overall, the function of the conceptual model is to guide decision making of others during an operation. First, it enables all parts of a commander's distributed forces to work in a coordinated fashion toward a single purpose, even though those parts may operate with little explicit coordination. Second, it bounds the information needs of the commander and enables subordinate commanders to pass along only that information concerned with the command concept. This reduces communication demands and makes C2 more effective.

Common Intent

Pigeau and McCann [54] have put forward a new definition of C2 as "The establishment of common intent to achieve coordinated action." Their definition is consistent with the notion of creating a conceptual model to serve as the basis for all decision making in an operation. In Pigeau and McCann's theory, "intent" includes all knowledge leading to achievement of the purpose and addresses the common understanding of all mission relevant matters (i.e. intent is more than just the purpose). To say that individuals have achieved common intent presupposes a quite rich and detailed mental representation shared in some way among many individuals working to a common end.

Pigeau and McCann divided intent into two parts, *explicit* and *implicit*. Explicit intent is publicly communicated directions such as written or verbal orders that convey a plan. The statement of commander's intent, the concept of operations, and all other formal documents contribute to explicit intent. Even with lengthy directives, not all intentions and details of how intentions are to be implemented can be expressed. The concept of implicit intent refers to all of the connotations latent in an explicit communication. It is the internalized collective and individual knowledge, expectations, and beliefs that are presumed upon to guide actions, consciously or otherwise. Implicit intent derives from the extensive knowledge bases people acquire through experience, such as beliefs, values, habits, expectations, and personal styles, in or out of the military. In many respects, implicit intent is like the complex, pre-existing knowledge structures needed to make sense of the world in constructive perception.

Thus, overall *common intent* (or shared intent) is derived from explicit and implicit intent and may be seen as the sum of all shared knowledge (however acquired) related to the implementation of a specific mission. This collective knowledge includes both goals and means and can be shared among many people representing different specialties. The composition of overall intent (explicit and implicit) within an individual is described in terms of an *intent hierarchy* (see Figure 3*)*. Figure 3, depicts the relative importance and influence of the different components of intent proposed by Pigeau and McCann. The top layer of explicit knowledge is derived from communications such as orders or directives related to the mission in question as well as dialogue about the mission in the form of discussion, questions, and answers.

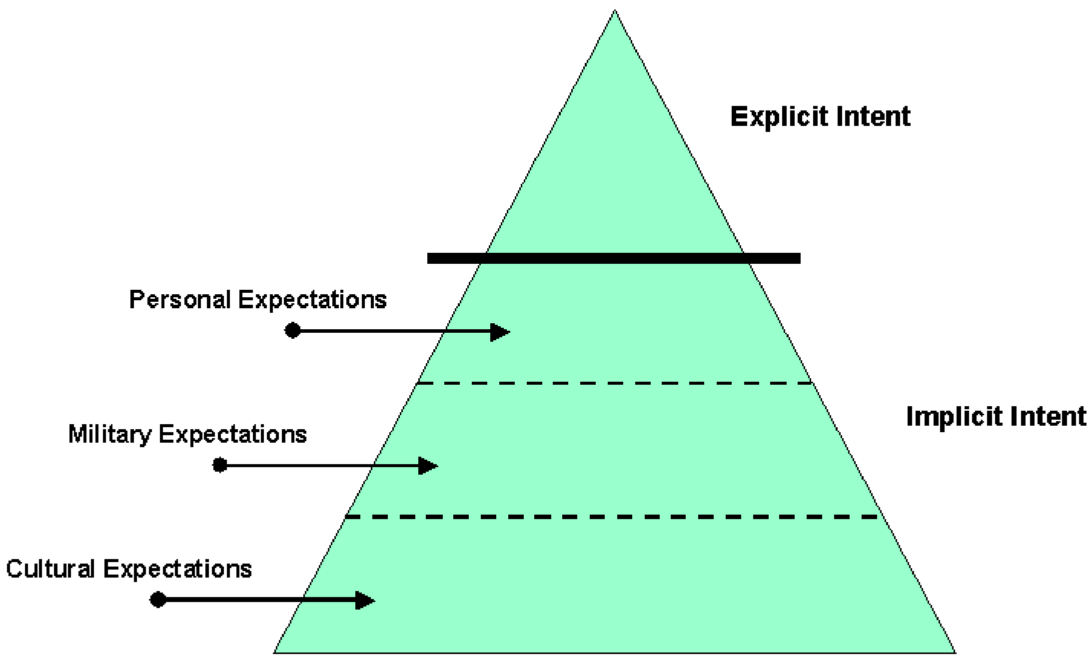

Figure 3. *Intent Hierarchy (Adapted from Pigeau & McCann [54])*

This explicit layer builds on further layers of implicit expectations based on personal, military and cultural education, training, and experience. These include, for example, expectations of how specific military procedures associated with the explicit orders should be executed. The personal layer is based, in its turn, on a larger, more influential layer of general military expectations. The military layer is comprised of doctrines and traditions that govern expectations about how to conduct oneself and relate to others and how operations should be carried out in general, not just specific orders for specific operations. Finally, this military layer is based on the broadest cultural expectations about national interests, societal and moral values. The lower the layer, the earlier its acquisition and the more enduring and resistant to change it is expected to be.

Establishing common intent is seen as critical for an organization to coordinate goal related efforts because common intent serves as a referent for members of the organization. They are able to compare the state of the mission at any given time to the common intent and then take any corrective action needed to ensure the organization's actions are working toward that intent.

Sharing intent during planning is critical to development of a shared conceptual model of how the operation is to proceed. As Figure 4 illustrates, individuals can only communicate through explicit intent, whether verbally, through writing, or diagrams. The content of explicit intent, however, depends on each individual’s implicit intent, which guides how they express their thoughts and how recipients understand what is communicated. It is through sharing explicit intent that each individual affects the common intent among the team as a whole. The conceptual model is that part of the shared intent that deals specifically with the operation, its goals, and the methods to be employed. The shared conceptual model may not be well defined because different individuals may understand the shared intent in somewhat different ways. The better the communication of the operational plan or command concepts (Builder et al., 1999), the more coherent and universal will be the shared conceptual model.

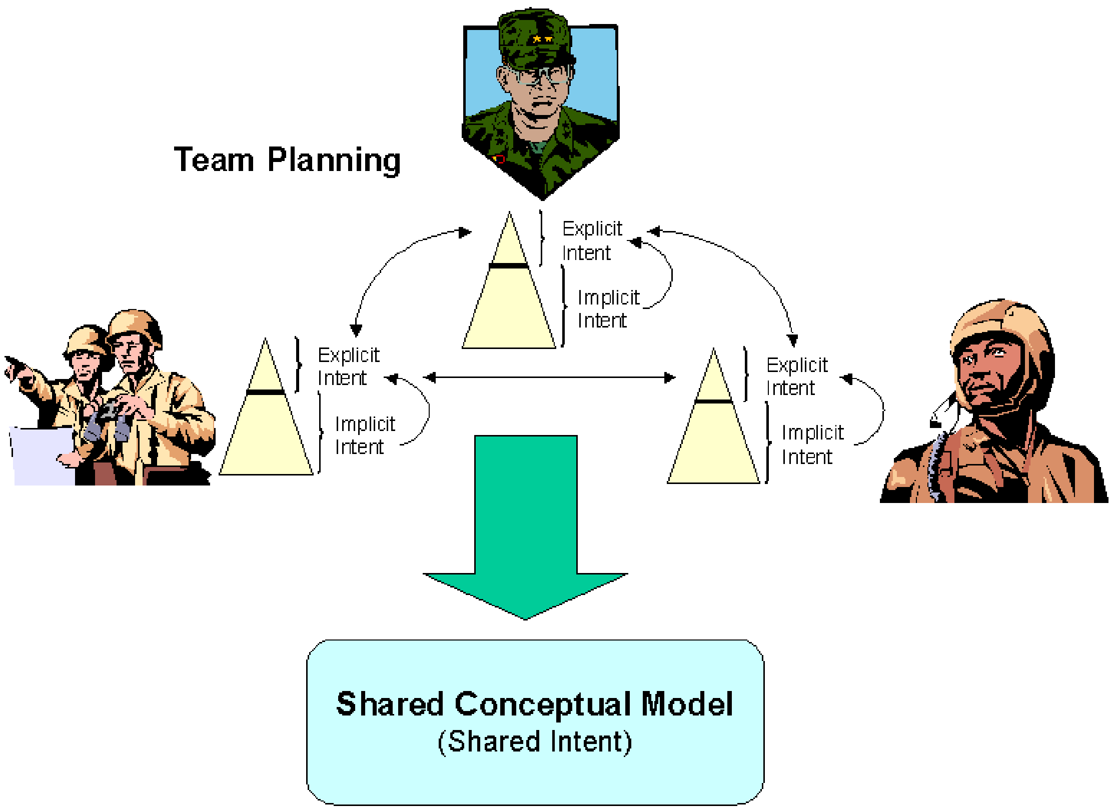

Figure 4. *Sharing Intent Leads to a Shared Conceptual Model*

C2 as a Decision Making System

The constructivist perspective on perception not only helps us to better understand how individuals make decisions, it can also serve as an analogy to the C2 organization itself. Wilson [20], for example, points out that armed forces are like a living organism in several respects (see also Coakley [18], pp. 41-43); in particular, like a biological organism, armed forces:

- Must interact with the physical environment, secure resources, pursue strategic aims, and avoid harm from potential adversaries;
- Rely heavily on sensor interaction with the world and coordinate actions with objects and events in that world; and
- Deal with time pressures and competing goals.

The implication of this analogy is that the C2 organization is like an organism's central nervous system, carrying out the all the functions that mediate sensor operations and action [18]. To create the most effective C2 organization possible, we must understand every aspect of the C2 process as it contributes to the ultimate situation-appropriate behaviour [20]. We should consider every aspect of the C2 process in terms of its relevance and effectiveness in modifying the behaviour of armed forces with respect to what sensor data reveals about the battlespace. Situation-appropriate behaviour is defined by the physical environment, one's own goals, and the actions of others, especially enemy forces, that have effects on the environment. Thus, appropriate actions can only be taken to the extent that sensors acquire relevant and accurate data and that data are processed in ways that allow appropriate modification of behaviour within a period of time dependent on the speed of events in the environment.

Time pressure creates for the C2 organization the same problem it does for an organism – the problem of taking in and processing all relevant information before events render that information no longer informative. Wilson [20] terms this a "representational bottleneck" and it corresponds to the C2 problem of maintaining a current picture of the battlespace. The problem becomes more difficult to solve as the pace of events quickens and as the C2 organization attempts to gather more and more data. To date, the preferred means of combating the representational bottleneck has been to employ greater technology to speed the processing of data. Although continued technological advances should continue to improve the speed with which data can be gathered and processed, there is already evidence that the amount of data that can be gathered is growing at a faster rate than the ability to process it [55]. Thus, another solution is needed to mitigate the representational bottleneck.

One potential solution is to make better use of an organizing framework in the representation of the battlespace. As human beings employ mental models and concepts to guide their perception and decision making, the C2 organization should create a conceptual model of the operation to be used in guiding data gathering and tactical picture compilation. Studies have flagged the lack of a clear conceptual framework among commanders and staff as a key limitation in operational planning [10]. Without a clear framework, the commander's information needs throughout an operation are ill-defined and subordinate commanders and sensor operators are unable to assess what information is needed and when it is needed, reducing the quality of the battlespace picture.

This is, of course, not a new idea; the Operational Planning Process (OPP) is designed to create a model through development of the Concept of Operations (CONOPs) and Statement of Commander's Intent. What I argue here is that these planning products are insufficient in their present form to handle the vast data processing requirements imposed by current information gathering technologies. Thus, by conceptual model, I mean that the C2 organization should employ a much more detailed description of how the operation is intended to proceed. In particular, a conceptual model of an operation must specify how the commander and staff frame the operation in terms of the objectives, critical factors, and dynamism [7]. The latter point is key; effective data processing will depend on a description of how the operation is to occur over time as well as in relation to space and resources. Data gathering and processing can then be more adaptive and change according to changing requirements over time.

The Directed Telescope

When conducting an operation, the commander needs the means to determine how well the plan, as represented in the conceptual model, is working. This means figuring out how to test the conceptual model against reality to ensure that assumptions are still valid and prescribed actions will still have the intended effects. The focus in C2 has for a long time been on improving our remote sensing capability to take in greater amounts of data. There is only so much value, however, that can be derived from simply increasing the quantity of data and a more purposive approach to data gathering is needed.

The "directed telescope" is a concept, described by Martin Van Creveld, that refers to the means used by commanders to obtain tactical information and disseminate critical orders [56]. Historically, the directed telescope has been implemented by specially selected and trained officers or agents who were directly responsible to the commander. These officers performed a range of information gathering functions but remained available to respond to the commander's needs as they arose.

The directed telescope has been a fundamental method for commanders to exercise C2 and reduce uncertainty in the battlespace, as has been illustrated by Griffin [57] in analyses of historical C2 structures from antiquity to the modern era. Griffin demonstrates that the directed telescope has proven critical to commanders as a means of obtaining critical battlespace information rapidly. Among the examples of early directed telescope organizations was Alexander the Great's *somatophylaxes*, officers who served personally under Alexander and whose duties included assisting in the command of separated columns of the army, acting as couriers, and reporting observations from areas of the battlefield Alexander himself could not see. Griffin also describes the example of Wellington's use of aides in Napoleonic times. So important were these aides in gathering information on the battlefield and, critically, about the condition of Wellington's own forces, that each general officer was assigned at least one aide. Similarly, Ulysses Grant made extensive use of aides during the American Civil War. Perhaps presaging modern concepts of command intent, Grant went to great lengths to communicate his intent to trusted aides. Grant explained how he saw a battle progressing, the plan of manoeuvre, and all other important aspects of the operation so that the aides could gather timely and accurate information that would inform Grant of the status of his concept of operations. In addition, the aides were charged with ensuring the accurate communication of Grant's intent to subordinate officers in the field. The aides acted as proxies for Grant so that he could, in a sense, be at multiple key points of the battlefield simultaneously, if not physically then in mind and spirit and intent. The aides were there to see that Grant's intent was enacted and guided responses to evolving conditions on the field. American and British staffs in World War II expanded this kind of system.

The concept of the directed telescope falls in line with what we know of constructivist knowledge acquisition. It essentially takes of place of the top-down processes of perception in guiding the commander and C2 structure in its bottom-up information gathering. The aides who made up the historical examples of the directed telescope took to subordinate levels the commander's intent or vision and took back the information that bore most directly on the commander's intent. Critically, they also took back information concerning events or conditions that went counter to the commander's intent and signalled the need for some adaptation. This sort of process, however implemented, seems critical for operational success [39].

Nevertheless, the concept of the directed telescope can be made more useful to today's C2 by adapting it in several ways. First, modern telecommunications technologies allow the directed telescope to be made up of more than just a system of aides. With access to many sensors and data processing systems distributed within the battlespace, commanders can now implement a directed telescope in the informational space of networked sensors and systems. Instead of sending human aides to different places, the commander can also use communications over distances to impart intent and receive critical information. Sensors can now even be semi-autonomous, which permits them to act with some of the independence of humans, reducing the demands of control.[5]

Technology alone, of course, is not the answer. In addition to the expansion of the ways commanders communicate and receive information, there needs to be an enhancement of critical thinking behind the use of the directed telescope. Perhaps the primary advantage of the directed telescope is that it allows the commander to be present (virtually) in multiple places and solve multiple problems simultaneously through the common intent established with subordinates. But establishing common intent is not necessarily easy [58]. The more the commander questions his or her plan, the better able is he/she to formulate specific command concepts to be disseminated and specific information needs to guide data collection in the field. Critical thinking translates into a better understanding of the critical aspects of the concept of operations and, hence, what data will be most telling about how well that concept is working. By getting negative indications quickly (because the commander is looking for them) helps the commander adapt better to dynamic events in the battlespace, even though there may remain considerable uncertainty.

[5] Increased access to sensors carries with it the risk that commanders will be tempted to micromanage. The CECA Loop is not intended to solve such problems but rather provide a framework in which to address questions about what is the appropriate level of sensor management.

The CECA Loop

This section describes the Critique-Explore-Compare-Adapt (CECA) Loop, a new model of decision making that is based on the constructivist view on cognition. The CECA Loop is intended to be a general description of decision making by individuals and by the C2 structure. As a model of individual decision making, the CECA Loop captures the central importance of mental models as the means to represent and make sense of the world. It also demonstrates the necessity of top-down guidance of perception. In the case of a C2 organization, the model describes information gathering and processing carried out by distributed units in which a single conceptual model (perhaps what is meant by the idea of the recognized picture) is created and maintained at the organizational level, although any individual within the organization may have knowledge of only a portion of the conceptual model. Note that the best way to do this must be a matter of careful debate and study. Advances in computer and communication technology afford opportunities to enhance data representation and access. At the organizational level, however, the conceptual model and top-down information gathering are essential as well. This section then discusses the benefits of the CECA Loop relative to the ubiquitous OODA Loop as a model of decision making.

A New Command Decision Making Loop

At the core of decision making by an individual is the mental model that guides perception and action. Similarly, the C2 organization requires a conceptual model, which is a shared representation of the plan of operations over time. The model also applies to the entire C2 organization because in a distributed force all individuals must operate with respect to the same concept of the operation. Thus, the conceptual model developed through planning by the commander and staff must be disseminated in a way that allows every member of the force to internalize an accurate representation of at least those aspects of the conceptual model that can be affected by that individual. The next section will demonstrate that making better use of the organizational framework provided by a conceptual model, C2 is improved in two key respects:

- The amount of data gathered is reduced because the conceptual model clearly specified what data is relevant (worth gathering) at each point in the operation; and

- The amount of data processing is reduced because the conceptual model identifies critical aspects of the operation, allowing data to be processed in the most efficient manner to address critical aspects (avoid unnecessary processing).

The CECA Loop is illustrated in Figure 5 below. It is a model of decision making that is more consistent with modern theories of human cognition than the OODA Loop (see [1]). In particular, the CECA Loop takes into account constructivist ideas of perception and mental representation. Because the CECA Loop is based on modern concepts, it is simple but nevertheless more useful than the OODA Loop in prescribing decision making procedures and support. This model is intended to replace the OODA Loop as a basis for thinking about and discussing decision making in the context of C2 doctrine, decision support development, and training.

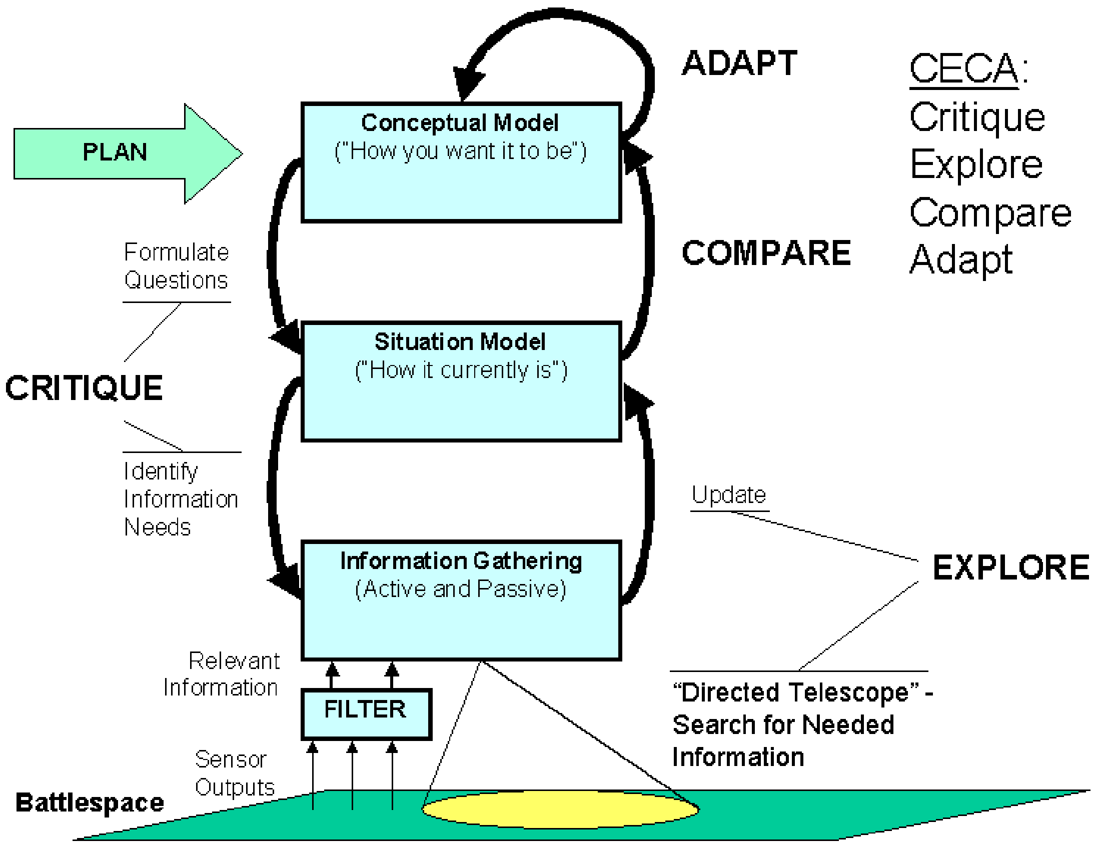

Figure 5. *The Critique, Explore, Compare, and Adapt (CECA) Loop*

The CECA Loop is explicitly based on the premise that goal-oriented mental models are central to human decision making as the means to represent and make sense of the world. It also demonstrates the necessity of top-down guidance of perception. The CECA loop begins with planning that establishes the initial *conceptual model*, which is a mental model of the plan. Throughout an operation, the conceptual model will be a representation of how the operation is intended to proceed and, thus, is closely aligned with the commander's intent. A *situation model* is also needed to represents the state of the battlespace at any given point in time.

The "Critique" phase of the CECA Loop comprises the establishment of information needs by first questioning the conceptual model to identify critical aspects that, if invalidated, would render the plan for the operation untenable in some respect. In essence, by asking how the current conceptual model might be invalid with respect to the battlespace, the commander focuses on those aspects most important to determine how the plan needs to be adapted to changing conditions. When questions are formulated, specific information needs (i.e. data to be collected) are identified and used to direct information gathering. Critiquing is based on the assumption that no plan is ever complete and that constant monitoring is needed to determine how the plan as modeled fails to coincide with reality.

The “Explore” phase of the CECA Loop comprises the active and passive collection of data from the battlespace. Active collection is guided by the information needs developed in the Critique phase. Active data collection is directed to answering questions of the conceptual model’s validity as quickly and accurately as possible. Passive collection is a filtering process in which events in the battlespace are monitored to determine whether aspects of the battlespace that are not being actively assessed should receive attention. When events trigger a response in the filtering system, those events can be actively processed and incorporated in the situation model and ultimately used to revise the conceptual model to deal with them appropriately. As data are collected, they are used to update the situation model to accurately represent the current state of battlespace. It is important to clearly distinguish data from information; the situation model is directly relatable to the conceptual model and hence informative about its validity.

In the “Compare” phase, the situation model is compared to the conceptual model to determine what, if any, aspects of the conceptual model are invalid (i.e. inconsistent with the current situation). It is then up to the decision maker to determine what to do in response to inconsistencies in the “Adapt” phase. In general, the decision maker has three options. He/she can chose to ignore the inconsistencies if they are deemed of low consequence (i.e. inconsistencies with the conceptual model have little practical impact). Not all discrepancies will affect major elements of the plan and in other cases the costs associated with rectifying a problem can exceed the expected benefits. A second option is to alter the means by which the goals represented in the conceptual model are to be achieved. This involves finding new solutions to problems that remove or bypass obstacles that arise as the operation proceeds. Finally, the most extreme option is alter the goals of the operation themselves, as well as actions represented in the conceptual model. This option is necessary when the most basic assumptions of the conceptual model are invalidated and there is no way to revise planned actions to meet the original goals.

Walkthrough the CECA Loop

The CECA loop begins with a plan. The plan should result from the OPP but its scope and level of detail depend on the nature of the operation being undertaken. The plan establishes the initial *conceptual model* (illustrated in the top-most box), which is a mental model of the plan. Throughout an operation, the conceptual model will be a representation of how the operation is intended to proceed and, thus, is closely aligned with commander’s intent. The conceptual model is parenthetically described (in Figure 5) as “how you want it to be” because this model maintains the goals of the operation as well as a representation of how to achieve them. These goals can change during an operation, in which case the conceptual model must be updated.

The second box depicts the situation model, which is a mental model that represents the state of the battlespace (“how it currently is”) as accurately as possible. The precise scope and level of detail of the situation model should be determined by the conceptual model. The situation model should represent all aspects of the battlespace that affect the validity of the conceptual model but not aspects that are irrelevant (as determined by the conceptual model specifically and doctrine generally). Although judging relevance is not always a simple matter, the key to effective information management depends on minimizing attention devoted to information that does not have the *potential* to invalidate the conceptual model. This is a critical point – disconfirmatory evidence, that which can indicate ways in which the conceptual model is not an accurate representation of how the operation is proceeding, is valuable, whereas confirmatory evidence is less informative.[6] People have a predisposition to seek information that will confirm their beliefs and plans [45] [59] but such evidence will yield only the continuance of those beliefs and plans. One may learn that one's assumptions still hold true but confirmation does not contribute to adaptation to changes in the environment. Evidence that disconfirms one's beliefs and plans, however, forces one to change them and, hence, one's actions to be more adaptive to the actual conditions of the battlespace. One cannot know before looking whether evidence will confirm or disconfirm an assumption but one can identify types of data that lack the potential to disconfirm any aspect of one's conceptual model (either because the data type does not bear on any aspect of the plan or the data lack the resolution or certainty to make a decision). For this reason, the focus of representing the situation should be on those elements of the battlespace with the greatest likelihood of yielding information that could potentially invalidate some aspect of the conceptual model. In this way, the conceptual model (including goals and planned actions) is maximally adaptive to actual conditions in the battlespace.

Finding relevant evidence with which to evaluate the conceptual model depends on the information gathering processes employed. Although the specific processes are a function of organization and technology, two general process types are available in C2. There is the top-down process of Search in which information gathering resources (both human and technological) are directed to look for specified types of information that have been identified as relevant. The best way to direct information search is to formulate questions or hypotheses about the relation of the current situation to the conceptual model. These questions should focus on the most important potential discrepancies that would signal a problem with the conceptual model. From the questions specific information needs are promulgated down to the sensor level so that the battlespace is searched with a kind of modern day "directed telescope" that provides desired information quickly.

The second means of information gathering is a bottom-up process in which sensors monitor the battlespace as widely as possible but pass up only information that meets specified criteria of relevance. This is illustrated by the box labeled *filter* in Figure 5, where the filter actually refers to all the mechanisms in place to block types of information that have been previously determined as irrelevant from further processing. A filtering process is necessary to prevent the decision maker and C2 organization from becoming overwhelmed by the volume of data that can be collected. It represents a compromise between the need to be responsive to unforeseen events that require reaction by the C2 organization and the limitations on the volume of data that can be processed at any given time. Setting appropriate criteria allow the system to detect and pass up relevant data that are not part of the active search process but block irrelevant information. Information that cannot disconfirm any aspect of the conceptual model is generally of no value because it cannot indicate whether some change in the

[6] I am drawing here an analogy between C2 and the practice of science, which depends on refutation of hypotheses to advance theoretical understanding. This analogy is not intended to mean that C2 affords the opportunity to strictly control conditions to set up tests of hypotheses.

conceptual model is needed, leaving the C2 organization to continue with its plan (which it could do without any confirmation). Understanding how to set filtering criteria requires a good understanding of the principles of warfare as well as the factors affecting the specific operation.

All gathered information is used to update the situation model to maintain a current representation of the actual battlespace. The situation model is compared to the conceptual model to determine what, if any, aspects of the conceptual model are invalid (i.e. inconsistent with the current situation). It is then up to the decision maker to determine what to do in response to inconsistencies. In general, the decision maker can chose to ignore the inconsistencies if they are deemed of low consequence (i.e. inconsistencies with the conceptual model have little practical impact), alter the means to goals represented in the conceptual model to determine new actions required to reach the original goals, or alter the goals as well as actions represented in the conceptual model.

Premises of the CECA Loop

The core premises of the CECA Loop, as a model of command decision making, can be summarized as follows:

1. A military operation, at any and all levels, must begin with a plan. Action without a well-defined model of what is to be accomplished and how it is to be accomplished cannot lead to desirable outcomes. Even the most broadly defined missions, such as surveillance, must begin with clear objectives and definitions of the kinds of objects and events of interest. Consequently, all command decision making depends on initial development of a plan.

2. A plan must be goal-directed and describe the *states* of the battlespace one wants to achieve across a specified period of time. This is much more important than describing what *actions* one believes should be performed to meet operational goals. Detailed specification of desired battlespace states is crucial for a) devising appropriate actions, b) assessing the effectiveness of actions in achieving desired battlespace states, and c) assessing the relevance and effectiveness of the plan itself (and goals) in meeting higher-level operational aims. Thus, the plan should clearly specify what is to be achieved in terms of a description of the state of the battlespace but be flexible with respect to how elements of the force will act to bring about those battlespace states. The plan becomes the basis of the conceptual model used in the decision making loop; in fact, it comprises the initial state of the model. The conceptual model can be thought of as a working description of what actions are to be taken at various times and the desired states of the battlespace that result from these actions. This is illustrated in Figure 6 where the conceptual model is depicted as a series of battlespace states. These begin with the initial state, established through planning, and end with the desired end-state comprising the operation objectives. In between are a series of desired transition states that define the path from the initial to desired end-state.

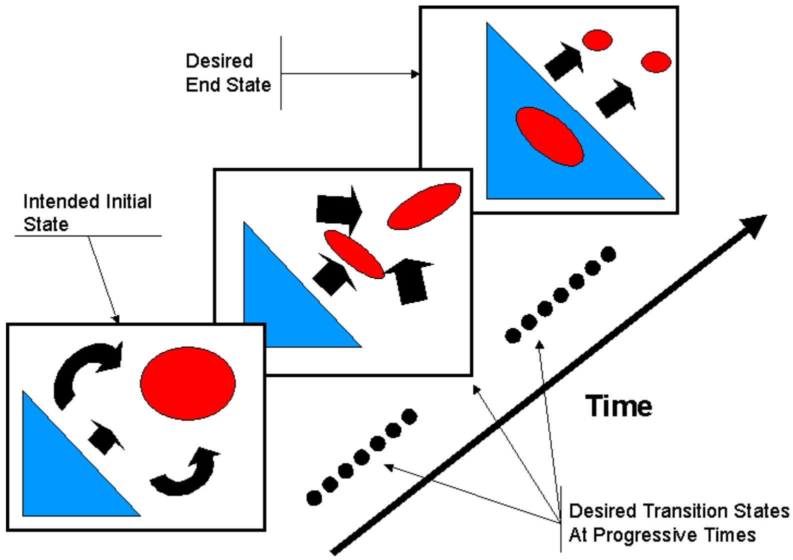

Figure 6. *The Conceptual Model Describes Intended States Over Time*

3. The plan must be understood in terms of a conceptual model that is *dynamic*. That is, the conceptual model should describe the states of the battlespace one wants and/or expects to occur over time as well as the ultimate desired end-state. As a working description, the conceptual model must be open to revision so that the desired transition states, and perhaps even the desired end state, can be changed in response to changes in the battlespace.

4. At any given moment, the actual state of the battlespace must be represented in a situation model that can be understood with respect to the conceptual model. In particular, the situation model must identify aspects of the current state of the battlespace that differ from the desired state of the conceptual model. Such differences indicate the critical points of divergence between the plan and the way events are unfolding and, hence, are thwarting achievement of goals or putting forces at risk.

5. Because the conceptual model of the plan is goal-oriented, information gathering and decision making must be *directed* toward determining the ways in which the current situation is facilitating the achievement of goals and more importantly the ways in which it is thwarting the achievement of goals. An adequate understanding of the implications of the situation for the plan cannot be gained passively. The conceptual model must be used to formulate *questions* about the current situation in relation to the conceptual model, specifically about the ways in which the current situation is facilitating or thwarting the achievement of goals, the resources and actions that can alter the situation toward meeting goals, and the ways in which potential actions will likely affect the battlespace. These questions serve as key elements in directing information gathering to relevant aspects of the battlespace and avoiding undue effort in gathering and processing irrelevant information (i.e. information that does not inform the status of the plan).

6. From the questions formulated with respect to the conceptual model, one must identify specific kinds of information and data types that will contribute to answering the

questions. Information gathering is then directed first and foremost to obtaining that information/data. Active search is akin to selective attention in humans, and serves to make optimal use of limited processing capacity to obtain relevant information rapidly and use it to compare the situation and conceptual models.

7. Although it is important to intelligently direct information gathering, one cannot be blind to all data types that have not been identified as necessary to answer questions. The wide range of sensors and information gathering technology available for the battlefield allows commanders to take in information about virtually every aspect of the battlespace. A portion of this information will be highly relevant to the status of the plan and in detecting and identifying new threats. However, because the volume of data outstrips our ability to process it thoroughly, a means to determine relevance at a low level of processing is needed. Thus, part of information gathering is the continual reception of sensor data, its filtering according to intelligently determined criteria, and the incorporation of relevant information into the situation model.

8. The criteria used to filter ambient sensor inputs must depend on the conceptual model, through analysis of the factors that can affect the achievement of goals or the safety of the force. This idea of excluding data from extensive processing may be controversial given current C2 practices, but the key to coping with the ever increasing amount of data being gathered is to develop robust means of limiting the amount of irrelevant data that consumes the limited attentional and cognitive capacity of decision makers. Biological models of perception and attention suggest the effectiveness of such system [19].

9. Data gathered through directed search (i.e. directed telescope) and filtering of ambient sensor inputs are used to update the situation model. Updating reflects changes that have occurred in the battlespace, corrections of errors in the situation model, the addition of missing elements, and the enhancement of relevant detail. All changes to the situation model must bear on the validity of the conceptual model to prevent the situation model from becoming overly complex with irrelevant information.

10. The updated situation model can be compared to the conceptual model as discussed above. With changes to the situation model, it is necessary to again identify elements of the current state of the battlespace that potentially affect achievement of goals or put forces at risk. Again, the emphasis should be on identifying ways in which the current state of the battlespace does not correspond to the state described by the conceptual model for this time period of the plan. In particular, the answers to the questions used to direct information gathering must be explicitly considered to ensure that the validity of critical aspects of the conceptual model are tested.

11. Based on the differences between the situation and conceptual models, the plan will require some degree of revision. Entering into an operation, the commander should accept the axiom that "no plan survives first contact with the enemy" and not only acknowledge the need for change but actively seek information that indicates the need for change. A commander should view the plan as a continually changing or dynamic guide that is described in the conceptual model, which can be continually compared to the situation model of the dynamic battlespace.

Putting the CECA Loop into Action

The CECA Loop, like the OODA Loop, is intended to serve as a framework in which to think about decision making in the context of C2. It is deliberately simplified to make it as widely applicable as possible and geared to the iterative nature of military operations. Nevertheless, the CECA Loop does suggest new practical approaches to C2 that are worthy of consideration.

Unlike the OODA Loop, the CECA Loop does not have "action" embedded in it. In part, I have attempted to keep the model simple and so Figure 5, which illustrates CECA, was made as uncluttered as possible by focusing on the cognitive aspects of C2. But on more substantiative grounds, there is a good reason to consider the information gathering/decision making loop in parallel to action. The OODA Loop places action at the end of a sequence of information processing activities and before the beginning of the subsequent sequence, implying a strict linearity to decision making – take in some data, think about what to do about it, then act in some way. Such linearity is rare in any system but especially so in a chaotic system like warfare, in which numerous streams of activities occur simultaneously.

Rather than view action as a stage within the model, the CECA Loop treats action as a continuous process in and of itself that is driven by the conceptual model, which is illustrated in Figure 7. According to the model, all actions are driven by the conceptual model, which lays out the rationale for each action the own force might take. As shown in Figure 7, the current state of the conceptual model (which depends on the data gathering and adaptation prior to this point) directs actions that affect the battlespace in some way. In fact, there will be numerous actions guided by the conceptual model at any point in time. The CECA Loop proper is shown in the figure as running in parallel with the direction of action by the conceptual model. As the conceptual model drives action it, at the same time, drives the data collection activities that allow the commander to assess the effects those actions (as well as the enemy's actions) have on the state of the battlespace. An important consequence of this assumption is that action is not strictly tied to immediate observations of the battlespace as in the OODA Loop. Rather, the conceptual model begins with a plan with the mission objectives at its core and evolves in relation to *all* observed events as they affect the validity of the plan. Where the OODA Loop gives the impression of a commander constantly reacting to external events, the CECA Loop shows how a commander remains focused on achieving his/her own goals as well as adapting to changes in the battlespace.

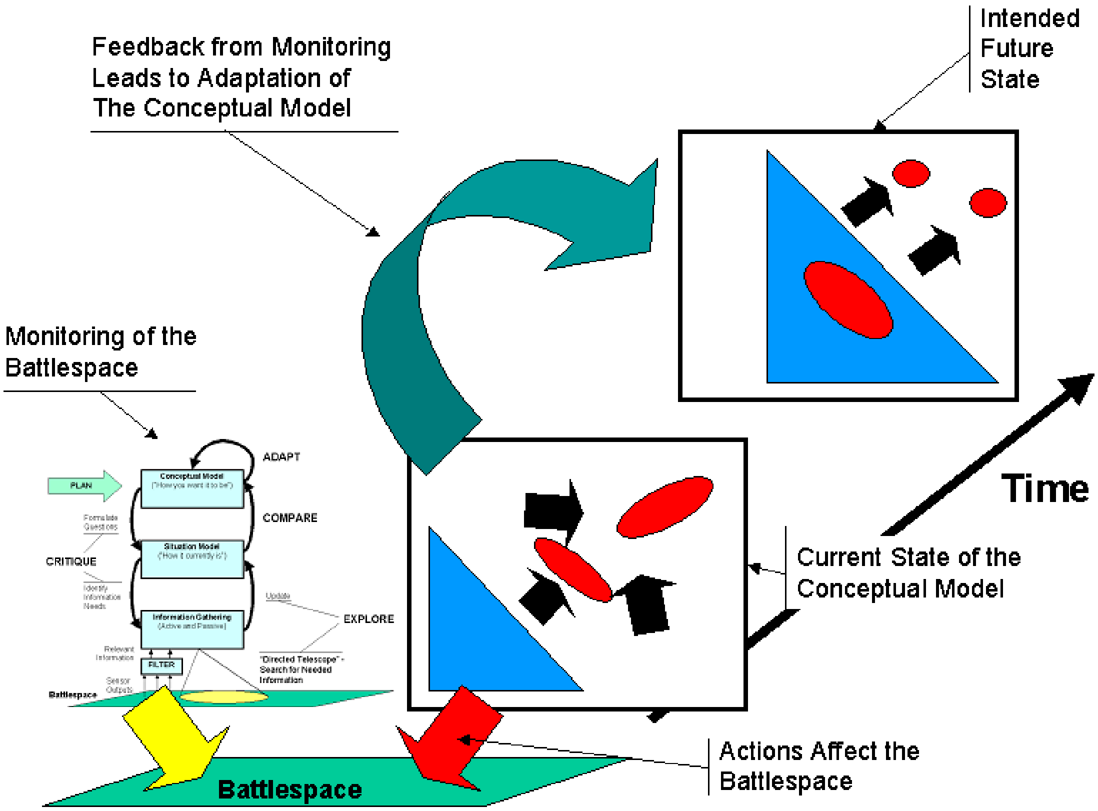

Figure 7. *Model-Guided Action and CECA Monitoring*

Adaptation in the conceptual model occurs as a result of the data collected through the CECA Loop that invalidates some aspect of the conceptual model. It is beyond the scope of this report to explore the problem solving techniques available to commanders but the model points to the need to explicitly consider how the decision making process once an operation is underway ties in with the operational planning process used in developing the initial plan (and hence the initial state of the conceptual model).

Two major departures from the OODA Loop mark the CECA Loop – the placement of the conceptual model at the centre of decision making activities and the specification of top-down information gathering processes. To bring planning and decision making into line with contemporary cognitive science, the OPP, Commander's Intent, Concept of Operations, and other formal parts of C2 need to be re-thought within the CECA framework. The conceptual model – the encompassing representation of how an operation is intended to proceed – cannot exist solely in the commander's mind. Sharing such a complex model, however, is difficult and effort needs to be devoted to creating an external conceptual model to which everyone in the C2 organization can refer.[7]

[7] Perhaps the difficulty and effort required to create and share a conceptual model contributed to the popularity of the OODA Loop as a decision making model – the OODA Loop simply ignores the representational issues involved in decision making.

Creating a sharable external conceptual model involves combining the physical, temporal, and cognitive elements of the commander's intent in an integrated form [2]. Time is an especially important factor because the conceptual model must be continuously evaluated with respect to the situation. This means more than just knowing how long actions are expected to take; it means knowing how elements of the battlespace are expected to evolve and change over time and as the result of actions taken by one's own forces and one's opponent [2]. An *event template* is a graphical representation of courses of action with time lines used in planning to show what activities will be done when and where [60]. Some product such as this could serve as a model for creating a more comprehensive graphical representation to serve as the shared conceptual model. If the CF pursues efforts to develop the Common Operating Picture to represent the state of the battlespace, it is essential to have a representation of the intended state of the planned operation in a compatible format.

Sharing the conceptual model will depend on the promulgation of shared intent. The shared conceptual model is not meant to be a huge document explaining every detail of the operational plan. Such micromanaging has proven ineffective (e.g., [61]). Rather, the conceptual model is meant to create a shared mental model among all members of the C2 organization and so must rely on extensive *implied intent* shared among those individuals [54]. A shared conceptual model can only be established if members of the C2 team have a base of shared concepts and values with which to interpret explicit products (written or graphical) that layout the time line and critical points of an operational plan.

The CECA Loop provides a strong rationale for increasing the adaptability of C2 systems. People naturally think in terms of a single conceptual model that guides their solutions to problems. It is critical, however, to continuously compare the model to reality, which can never be adequately foreseen, and to revise the conceptual model when it is disconfirmed. Higby [51] argues that C2 systems, like people, work best when they are designed to strike a balance between stable but uncreative linear structure and chaotic nonlinear structure. Putting a conceptual model at the heart of C2 provides the stability whereas continual monitoring and reaction to fluctuations in the battlespace provides the capacity to adapt appropriately. This requires an organization in which the top of the chain of command relinquishes some degree of direct control and pushes initiative down the chain of command. The people closer to the physical events occurring in the battlespace are better able to adapt. These people, however, must have a strong framework in which to generate actions that are consistent with the commander's intent and coordinated with other units. In addition, higher levels of command must trust the capabilities at lower levels and subordinate levels must trust their superiors to welcome and value disconfirmatory information.

The second departure from earlier views of decision making is the need to encourage and support top-down data gathering procedures. This means that there needs to be a change in orientation away from passive, bottom-up reception of sensor data to a guided process of active search. In particular, the search for disconfirming evidence, data that can show part(s) of the conceptual model to be invalid or flawed, is of paramount importance. Disconfirming evidence is informative and the search for it promotes efficiency in data gathering. To maintain initiative, a commander must continually test the assumptions underlying his/her plan. Studies of expert command decision making show that active search, sometimes termed "reflective thought," is a good description of what commanders actually do [37]. Marr [2] argues that an operational plan should include some form of reflective procedures to assess information needs and specify how information will be gathered and communicated within the organization.

From the bottom-up perspective, the CECA Loop makes clear that information cannot be treated as an infinitely valuable resource. Given limitations on the capacity to update mental models, human decision makers need to be economical in their use of information. Thus, to foster faster, better decision making actually requires a *decrease* in the amount of information that is passed through a C2 organization. Although the temptation might be to gather as much data as technology allows, that data will be of no use if there is not a concomitant capacity to process it into meaningful information that can be used to influence actions. The CECA Loop contains an explicit filtering function precisely to avoid overwhelming decision makers as they update their situation model. The criteria by which sensor data are filtered must be carefully determined on the basis of the operational plan and considerations of the terrain, opponent, and other contextual factors. In concert with active search, the filter provides the capability for the C2 organization to react to unanticipated events but limits the expenditure of information processing resources on irrelevant data.

Naturalistic decision making involves the balancing of a number of frequently conflicting requirements, including timeliness, accuracy, and frugality of information use [62]. This is manifested in the CECA Loop in the balance of top-down processing, guided by the conceptual model, with bottom-up, sensor-driven processing. A danger of making the conceptual model the focus of decision making is that the formulation of that model during planning may leave out key factors that will become important during the course of the operation. No one can anticipate every potential event, which means a commander will not be able to specify an exclusive set of information needs that define everything that potentially will bear on the conceptual model but exclude everything that will not.

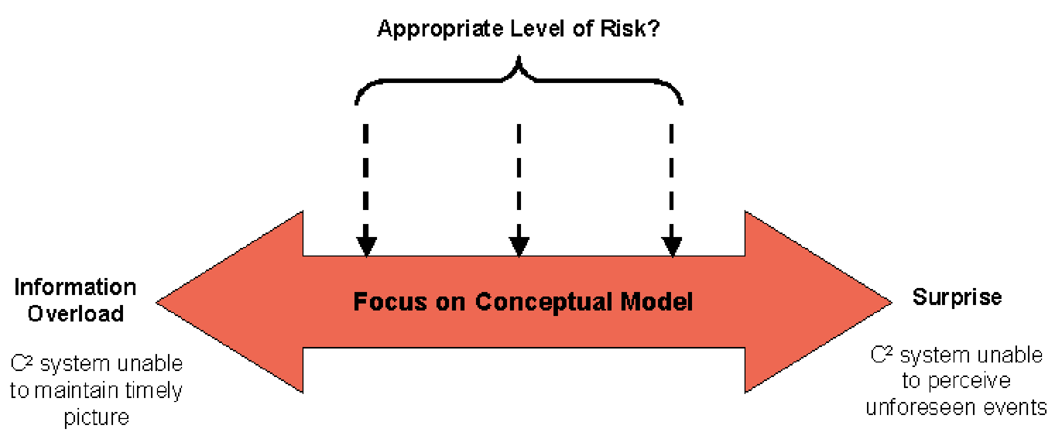

Figure 8. *Balancing Risk with Respect to the Conceptual Model*

In other words, as Figure 8 illustrates, in using the conceptual model to define the kinds of information one will seek, one risks excluding information that does bear on the operation but is excluded from the conceptual model, leading to surprise. This is akin to a man so intent on finding a needle in a haystack that he looks only for the glint of metal and neglects to notice the movement of a snake in the hay. Surprise is at least an equally undesirable outcome as information overload. In either case, the C2 system will be unable to act appropriately with respect to events that affect the force and operation.

The role of the CECA Loop model is not to advocate a highly conceptual orientation to decision making. Instead, by describing how people naturally tend to think, it provides a better framework for exploring the balance of risk of information overload and surprise than does the OODA Loop. Exactly how to set information needs based on the conceptual model is a question that must be studied empirically. It is clear that neither extreme, completely focusing on the model (leading to surprise) nor attempting to process all available data (leading to information overload), is a workable procedure. For this reason, the CECA Loop explicitly contains a filtering mechanism in addition to the directed telescope. The filter allows the system to be responsive to unanticipated events but put limits on how much resources are devoted to factors outside the conceptual model. Unlike the OODA Loop, the CECA Loop immediately makes clear that we need to assess the exact parameters to put on the filter and the level of detail that is appropriate for specifying top-down information requirements.

Advantages of the CECA Loop

Because the CECA Loop is more consistent with current theories of human decision making, it offers several advantages over the OODA Loop.

1. First, the CECA Loop makes clear that data and information are relative to the decision maker. The Observe stage of the OODA Loop is entirely passive and treats information as a thing in the outside world, suggesting that one key to decision making is amount of information that can be gathered. In contrast, the CECA, with its focus on comparing a situation model to one's conceptual model, correctly recognizes that data arises from the interaction of sensors with the environment and information from the interaction of sensor data with existing representations of the environment. Thus, there is no such thing as objective information that exists in the environment waiting to be gathered. Instead, there is a physical world to be interacted with in ways that are governed by goals and beliefs. This makes clear that the amount of data is not the paramount factor but the *informativeness* of that data in terms of allowing the decision maker to evaluate the validity of his or her mental models. The information needed and derived from any environment depends on the objectives of the individual, which determines the sorts of relevant questions about how the world is conceived and how it really is. An important consideration in applying this model to C2 is that different individuals within an organization will have different goals and hence different information needs. The idea of a common operating picture consisting of all gathered information and viewed in the same way by all members of the C2 organization is a fallacy.

2. A second advantage of the CECA Loop is that is puts the concept of a conceptual model at the centre of decision making. The conceptual model is the link between planning and action because it is a detailed representation of the objectives of the operation, the principles that guide how those goals are to be achieved, and a general outline of the actions that must be taken over time. The importance of this linkage is recognized in CF doctrine and theories of human decision making, that people naturally build mental

models to represent problems as they work on them and that these models are at the centre of decision making activities. Critically, the quality of the plan/conceptual model determines the quality of the questions and hypotheses drawn by the decision maker and used to search for information. Thus, in considering how to improve and speed up the decision making process, it is critical to examine how changes to procedures or technology will affect the representation of the plan. Changes that seem to enhance procedural aspects of decision making may actually impair overall performance if they disrupt the formulation or understanding of the conceptual model. On a more positive note, changes to the planning procedure or communication of the plan throughout the C2 organization could yield significant benefits to decision making by making it easier for individuals to identify relevant information and use it appropriately. There is definitely a need to advance doctrine and training with respect to how to plan well and derive the best information search strategies from the plan.

3. Perhaps one of the greatest advantages of the CECA loop is the emphasis on testing one's assumptions by seeking disconfirming evidence and updating the situation model. Because the conceptual model provides the understanding of the battlespace used to make inferences and guide actions, it is critically important to ask whether one's conceptual model provides a valid description of the battlespace. Where the conceptual model is wrong is where the greatest potential for errors in judgment lies. By actively seeking information that indicates aspects of the conceptual model that are invalid or inadequate, the decision maker can quickly correct those problems. Data that is consistent with a conceptual model is less informative because it does not alter one's understanding. We must accept that the human mind cannot have perfect knowledge of the external universe, in which case a mental model is merely the best representation possible given what one knows. Confirmatory evidence is simply information that is already implied by the existing model; i.e. it is explained within the representation. Disconfirmatory evidence, on the other hand, is not explainable within the model and so signals an error in the representation of the situation. This is informative, telling one, at the least, that some part of one's mental representation is flawed. That is the first step in determining a better, more explanatory model. As the decision maker creatively alters the conceptual model, he or she devises a description or explanation of the battlespace that is closer to the truth and more useful in guiding actions.[8]

[8] The bias to seek confirming evidence can hinder creativity in problem solving. Looking for evidence that "breaks" one's plan fosters creativity and the consideration of alternative ways of solving a problem.

Conclusion

Summary

In this report, I have argued that the OODA Loop is no longer an adequate model of decision making in C2. Boyd developed the model roughly 50 years ago and it has received little critical evaluation since that time. In fact, the OODA Loop obscures a number of important aspects of human decision making that are important to effective C2; in particular the central role of knowledge representation and the active, constructive nature of perception and understanding.

The major advances in cognitive science over the last half-century should be considered in a model used to discuss decision making. Although the full range of progress cannot be detailed here, four main themes were identified:

1. Cognition is goal-directed;

2. Perception and understanding are constructive processes;

3. Mental models are used to represent complex and dynamic situations and problems; and

4. Critical thinking enhances decision making.

These aspects of cognition are recognized to some degree in recent theories of C2, such as command concepts [39] and common intent [54].

In response to the need for a more up-to-date decision making model, I have proposed the CECA Loop, which incorporates the cognitive themes mentioned above. At the core of this model is the conceptual model. Based on a plan, the conceptual model describes how the operation or mission is to proceed over time and guides both action and information gathering. The major processes in the model are Critique (comprising active questioning of the conceptual model and operationally defining information needs), Explore (both active and passive data collection), Compare (data are used to update a situation model that serves as a referent for the conceptual model), and Adapt (altering the conceptual model in ways that address mismatches between the current situation and the prescribe state according to the conceptual model).

I argue that the CECA Loop provides not only a better description of natural, human decision making but also provides a better framework in which to discuss C2 issues than the OODA Loop. Where the OODA Loop obscures issues of representation and constructive understanding, the CECA Loop makes clear that important decisions need to be made about the C2 process itself. Based on the CECA Loop, for example, it is clear that the nature of the conceptual model must be made explicit and agreed upon by all members of the organization, knowing that a balance must be struck between processing too much information, and risking information overload, and relying too exclusively on the pre-defined conceptual model, and risking surprise due to unanticipated events. Similarly, the CECA Loop points out the importance of asking the right questions about the battlespace to ensure that data collection is efficient and helps the organization adapt to conditions. The OODA Loop emphasizes only the speed with which decision making activities are performed but the CECA Loop opens up the cognitive domain of decision making to explore issues of *how* we should perform decision processes. Although the CECA Loop provides a more accurate –if general – description of human decision making, the greatest value of this model lies in its capacity to serve as a framework for asking questions about how to best support C2, planning, and other operational procedures.

Recommendations

Based on the discussion of modern perspectives in cognitive psychology and the presentation of the CECA Loop, it is possible to put forward a few broad recommendations to the Canadian Forces regarding its approach to planning and decision making. By necessity these recommendations cannot offer very specific guidance; the CECA Loop model is intended first as a framework in which to *raise* questions and then consider practical ways to improve human performance. Nevertheless, the five recommendations below could set the stage for dramatic changes in the way data gathering and C2 are viewed by the CF. The CECA Loop model presents a view of cognition that suggests greater emphasis in C2 organizations should be placed on top-down guidance rather than bottom-up data collection. In particular, the model forces decision makers to confront the trade-off of speed and efficiency with the amount of raw data sampling from the physical world inherent in any perceptual system. Debate of these issues can only strengthen the CF's understanding of C2 concepts appropriate to the 21st century battlespace.

The five recommendations are as follows:

1. **Incorporate cognitive theory in doctrine:** Perhaps the main point of this report is that the CF needs to think about and decide upon a model of human cognition. An understanding of human cognition is becoming increasingly important to the development of decision support and training but, as with the case of the OODA Loop, the models adopted have not necessarily been thoroughly evaluated. The CECA Loop can serve as a starting point in this process as a guide to research and development. However, we must be prepared to engage in continual and explicit consideration of the cognitive model to keep it up to date with advances in the cognitive sciences.

2. **Put the conceptual model at the heart of planning and decision making:** This recommendation amounts to a call for the development of more integrative means by which to describe and propagate the plan. Currently the CONOPS, Commander's Intent, and other products of the OPP establish a "model" for an operation. It is not clear, however, how well these products can be synthesized to create the kind of unified mental model that embodies the conceptual model.

3. **Put the situation model at the heart of picture compilation:** Picture compilation is the process of creating and maintaining a description of the battlespace. By shifting from the picture metaphor to the mental model, however, it becomes clearer that what

needs to be shared is not raw data but the representation of objects and their inter-relations in the battlespace. The concept of the situation model that describes the current state of the battlespace at each moment in time is consistent with the role of mental models in human cognition and provides a basis for greater critical evaluation of the conceptual model. The situation model, however, must be sharable within and across levels of command and this is an area greatly in need of research. Research on team communication has found that achieving complex shared understanding is not a simple thing (e.g., [58]). Creating support for sharing a situation model should be a focus for future research efforts.

4. **Acknowledge the constructive nature of perception and understanding:** Human cognition is strongly proactive and goal-directed. Thus, human beings do not rely exclusively on passive reception of sensory data to understand the world; rather, people actively attempt to make sense of the vast amount of sensory data taken in by applying pre-existing concepts and mental models. The advantages of constructive perception is that less data need be processed and the data that are collected can be more efficiently integrated to build a representation of the outside world. By placing the conceptual and situation models at the heart of C2, we can gain similar advantages, as long as procedures and systems are designed to capitalize on the CF's organizational knowledge. A major role of the conceptual model is to guide data collection and it is here that perhaps the greatest progress is to be made in bringing C2 doctrine more in line with human cognitive processes. Rather than trying to abolish all potential biases from data gathering, which is unrealistic, it is better to accept the fundamental role of a mental model in human cognition and work to use that model productively. Guiding data collection with the conceptual model focuses effort and takes advantage of the experience and knowledge of commanders and staff.

5. **Increase the role of critical thinking in C2:** Data collection should serve the function of answering critical questions pertaining to the validity of the conceptual model. To this end, decision makers in the loop must be prepared to seek evidence that could potentially disconfirm the plan. If, however, "no plan survives first contact with the enemy," then disconfirmation is inevitable. It is best to discover how the plan has diverged from the true state of the battlespace as quickly as possible. The conceptual model should be considered a "living" representation of the plan, to be changed as needed. The purpose of seeking disconfirming evidence is to be able to respond to changing circumstances quickly and adapt the plan appropriately.

References

1. Alex, C. (2000). *Process and procedure: The tactical decision-making process and decision point tactics* (Unpublished Master's Thesis). Fort Leavenworth, KS: Army Command and General Staff College.

2. Marr, J. (2001). *The military decision making process: Making better decisions versus making decisions better* (Monograph). Fort Leavenworth, KS: Army Command and General Staff College.

3. Cunningham, K. (2000). *Bounded rationality and complex process coupling: Challenges for intelligence support to information warfare* (Strategic Research Report). Carlisle Barracks, PA: Army War College.

4. Sparling, B. (2002). *Information theory as a foundation for military operations in the 21st century* (Monograph). Fort Leavenworth, KS: Army Command and General Staff College.

5. Litherland, J. (1999). *The command and control dilemma of Joint Vision 2010* (Final Report). Newport, RI: Joint Military Operations Department, Naval War College.

6. Ogilvie, D. T. (1998). Creative action as a dynamic strategy: Using imagination to improve strategic solutions in unstable environments. *Journal of Business Research, 41*, 49-56.

7. Loffert, J. (2002). *Mission analysis: Giving commanders what they need* (Monograph). Fort Leavenworth, KS: Army Command and General Staff College.

8. Plehn, M. (2000). *Control warfare: Inside the OODA loop*. Unpublished Master's Thesis, Air University, School of Advanced Airpower Studies, Maxwell AFB, AL.

9. Sweeney, M. (2002). *An introduction to command and control* (Unpublished Master's Thesis). Monterey, CA: Naval Postgraduate School.

10. Cook, T. M., Leedom, D. K., Grynovicki, J. O., & Golden, M. G. (2000). *Cognitive representativeness of battlespace complexity: Six fundamental variables of combat* (Final Report ARL-TN-155). Aberdeen Proving Ground, MD: Army Research Laboratory, Human Research and Engineering Directorate.

11. Giffin, R. E. (2002). Superstitious rituals: Naïve inductivism in command and control doctrine: Its causes, consequences and cures." *Proceedings of the 7th International Command and Control Research and Technology Symposium*. Quebec City, QC. Command and Control Research Program, Department of Defense.

12. Popper, K. R. (1992). *The logic of scientific discovery*. New York, NY: Routledge.

13. Rock, I. (1997). *The concept of indirect perception*. In Rock, I. (Ed.) *Indirect perception* (pp. 5-15). Cambridge, MA: The MIT Press.

14. Gibson, J. J. (1979). *The ecological approach to visual perception*. Boston, MA: Houghton Mifflin.

15. Helmholtz, H. von. ([1867], 1962). *Treatise on physiological optics*, vol. 3. Translated from the German by J. P. C. Southall. New York, NY: Dover.

16. Palmer, J. A., & Palmer, L. K. (2002). *Evolutionary psychology: The ultimate origins of human behavior*. Boston, MA: Allyn and Bacon.

17. Bisanz, J., Bisanz, G. L., & Kail, R. (Eds.). (1983). *Learning in children: Progress in cognitive development research*. New York, NY: Springer-Verlag.

18. Coakley, T. P. (1992). *Command and control for war and peace*. Washington, DC: National Defense University Press.

19. Rock., I. (1993). *The logic of perception*. Cambridge, MA: The MIT Press.

20. Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review, 9,* 625-636.

21. Hatano, G., & Inagaki, K. (2000). *Knowledge acquisition and use in higher-order cognition*. In K. Pawlik & M. R. Rosenzweig (Eds.), International handbook of psychology (pp. 167-190). London, England: Sage Publications.

22. Jansson, A. (1999). Goal achievement and mental models in everday decision making. In P. Juslin & H. Montgomery (Eds.), *Judgment and decision making: Neo-Brunswikian and process-tracing approaches* (pp. 23-43). Mahwah, NJ: Lawrence Erlbaum Associates.

23. Newell, A., & Simon, H. A. (1972). *Human problem solving*. Englewood Cliffs, NJ: Prentice-Hall.

24. Peschl, M. F. (1992). The art of constructing knowledge in natural and artificial cognitive systems from the perspective of computational neuro-epistemology. *Cognitive Systems, 3*, 219-240.

25. Von Glasersfeld, E. (1995). *Radical constructivism: A way of knowing and learning*. London, England: Falmer Press.

26. Potter, J. (1996). *Representing reality: Discourse, rhetoric and social construction*. Thousand Oaks, CA: Sage.

27. Gregory, R. L. (1980). *Perception as hypotheses*. Philosophical Transactions of the Royal Society of London, Series B, 290, 181-197.

28. Shepard, R. N. (1990). *Mind sights: Original visual illusions, ambiguities, and other anomalies, with a commentary on the play of mind in perception and art*. New York, NY: Freeman and Company.

29. Johnson-Laird, P. N. (1983). *Mental models*. Cambridge, MA: Harvard University Press.

30. Garnham, A. (1997). *Representing information in mental models*. In M. A. Conway (Ed.), Cognitive models of memory. Studies in cognition (pp. 149-172). Cambridge, MA: The MIT Press.

31. Sahlin, N.-E. (1991). Baconian inductivism in research on human decision-making. *Theory and Psychology*, 1, 431-450.

32. Yilmaz, M. R. (1997). In defense of a constructive, information-based approach to decision theory. *Theory and Decision, 43*, 21-44.

33. Moray, N. (1999). *Mental models in theory and practice*. In D. Gopher & A. Koriat (Eds.), Attention and performance XVII: Cognitive regulation of performance: Interaction of theory and application (pp. 223-258). Cambridge, MA: The MIT Press.

34. Rouse, W. B., Cannon-Bowers, J. A., & Salas, E. (1992). The role of mental models in team performance in complex systems. *IEEE Transactions on Systems, Man and Cybernetics, 22*(6), 1296-1308.

35. Fiore, S. M., Salas, E., & Cannon-Bowers, J. A. (2001). *Group dynamics and shared mental model development*. In M. London (Ed.), How people evaluate others in organizations. Applied in psychology (pp. 309-331). Mahwah, NJ: Lawrence Erlbaum Associates.

36. Rickheit, G., & Sichelschmidt, L. (1999). *Mental models: Some answers, some questions, some suggestions*. In G. Rickheit & C. Habel (Eds.), *Mental models in discourse processing and reasoning* (pp. 9-40). Amsterdam, Netherlands: North-Holland/Elsevier Science Publishers.

37. Whitehurst, S. (2002). *Reducing the fog of war: Linking tactical war gaming to critical thinking* (Monograph). Fort Leavenworth, KS: Army Command and General Staff College.

38. Basar, T., & Cruz Jr., J. B. (1984). *Robust Team-Optimal and Leader-Follower Policies for Decision Making in C3 Systems* (Final Report ONR Contract No. N00014-82-K-0469). Arlington, VA: Office of Naval Research.

39. Builder, C. H., Bankes, S. C., & Nordin, R. (1999). *Command concepts: A theory derived from the practice of command and control*. Santa Monica, CA: Rand Corporation.

40. Heffner, T. S. (1997). *Training Teams: The Impact of Task and Team Skills Training on the Relationship Between Mental Models and Team Performance.* Unpublished doctoral dissertation, Pennsylvannia State University.

41. Mohammed, S. (1996). *Toward an Understanding of the Antecedents and Consequences of Shared Frames in a Group Decision-Making Context.* Unpublished doctoral dissertation, Ohio State University.

42. Entin, E. B., Entin, E. E., MacMillan, J., & Serfaty, D. (1993). *Structuring and Training High-Reliability Teams: Year 1 Technical Report* (Technical Report TR-599). Fort Rucker, AL: U.S. Army Research Institute/Aviation R&D Activity.

43. Kraiger, K., & Wenzel, L. H. (1997). Conceptual Development and Empirical Evaluation of Measures of Shared Mental Models as Indicators of Team Effectiveness, *Team Performance Assessment and Measurement: Theory, Methods, and Applications* (pp. 63-84). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

44. Shattuck, L. G. (1996). *Communication of Intent in Distributed Supervisory Control Systems.* Unpublished Dissertation, Ohio State University.

45. Green, D. W. (1990). Confirmation bias, problem-solving and cognitive models. In Caverni, J-P. & Fabre, J-M. (Eds.), Cognitive Biases (pp. 553-562). Oxford, England: North-Holland.

46. Emilio, G. (2000). *Promoting critical thinking in professional military education* (Research Report AU/ACSC/058/2000-04). Maxwell AFB, AL: Air Command and Staff College.

47. Riedel, S. (2001). *Training critical thinking skills for battle command: ARI workshop proceedings* (Final Report). Alexandra, VA: Army Research Institute for the Behavioral and Social Sciences.

48. Cohen, M. S., Freeman, J. T., & Thompson, B. (1998). *Critical thinking skills in tactical decision making: A model and a training strategy*. In J. A. Cannon-Bowers & E. Salas (Eds.), Making decisions under stress: Implications for individual and team training (pp. 155-189). Washington, DC: American Psychological Association.

49. Brehmer, B. (1986). *In one word: Not from experience*. In H. R. Arkes & K. R. Hammond (Eds.), Judgment and decision making: An interdisciplinary reader (pp. 705-719). New York, NY: Cambridge University Press.

50. Radecki, C. M., & Jaccard, J. (1995). Perceptions of knowledge, actual knowledge, and information search behavior. *Journal of Experimental Social Psychology, 31*, 107-138.

51. Higby, P. (2000). *Economy of information: A necessary principle of war* (Final Report). Newport, RI: Naval War College, Joint Military Operations Department.

52. Patrick, F. (2000). The *Third Wave Metanoia: Breaking the Command and Control Paradigm* (AD-a378 472). Newport, RI: Naval War College.

53. Bryant, D. J., Webb, R. D. G., Matthews, M. L., & Hausdorf, P., 2001. *Common intent: Literature review and research plan*. Report to Defence and Civil Institute of

Environmental Medicine (CR 2001 041). Human*systems* Incorporated, Guelph, ON, Canada.

54. Pigeau, R., & McCann, C. (2000). *Redefining command and control*. In McCann, C. & Pigeau, R. (Eds.), The human in command: Exploring the modern military experience (pp. 163-184). New York, NY: Kluwer Academic/Plenum Publishers.

55. Beaver, M. (2001). *Dealing with information overload: Ockham's Razor in the hands of the Joint Force Commander* (Technical Report AD-A392 894). Newport, RI: Naval War College.

56. Van Creveld, M. (1979). *Command*. Washington, DC: Department of Defence.

57. Griffin, G. B. (1992). *The directed telescope: A traditional element of effective command* (Combat Studies Institute Report). Fort Leavenworth, KS: U.S. Army Command and General Staff College.

58. Shattuck, L. G., & Woods, D. D. (2000). *Communication of intent in military command and control systems*. In C. McCann & R. Pigeau (Eds.), The human in command: Exploring the modern military experience (pp. 279-291). New York, NY: Kluwer Academic / Plenum Publishers.

59. Evans, J. S. B. T. (1987). *Beliefs and expectations as causes of judgmental bias*. In G. Wright & P. Ayton (Eds.), Judgmental forecasting (pp. 31-47). Oxford, England: John Wiley & Sons.

60. Innocenti, C. (2001). *Abbreviated military decision making for brigade combat teams* (Unpublished Master's Thesis). Fort Leavenworth, KS: Army Command and General Staff College.

61. Dumas, R. (2002). *Micromanagement and a Commander's Lack of Operational Vision: A Case Study of Operation Allied Force* (AD-a405 926). Newport, RI: Naval War College.

62. Bryant, D. J. (2002). Making naturalistic decision making “fast and frugal.” *Proceedings of the 7th International Command and Control Research and Technology Symposium*. Quebec City, QC. Command and Control Research Program, Department of Defense.

List of symbols/abbreviations/acronyms/initialisms

C2	Command and Control
CECA	Critique-Explore-Compare-Adapt
CF	Canadian Forces
CONOPS	Concept of Operations
DND	Department of National Defence
OODA	Observe-Orient-Decide-Act
OPP	Operational Planning Process

Glossary

Technical term	Explanation of term
Command Concepts	"A vision of a prospective military operation that informs the making of command decisions during that operation" [39].
Conceptual Model	A dynamic mental model that represents how an operation is intended to proceed over time that maintains the goals of the operation as well as a representation of how to achieve them.
Constructive Perception	Theoretical perspective that describes perception and comprehension in terms of active, inference-making processes that work to select, modify, and interpret sensory data to create a coherent and meaningful understanding of the physical world.
Critical Thinking	The systematic questioning and evaluation of one's own reasoning strategies; similar to hypothesis testing.
Directed Telescope	The means used by commanders to obtain tactical information and disseminate critical orders; historically implemented by specially selected and trained officers or agents who were directly responsible to the commander.
Disconfirmatory evidence	Information that can potentially indicate ways in which one's assumptions or beliefs are inaccurate or invalid; indicates events in the environment that are not explainable within one's conceptual model and so signals an error in the representation of the situation.
Explicit Intent	Publicly communicated directions such as written or verbal orders that convey a plan; e.g., the statement of commander's intent, the concept of operations, and all other formal documents contribute to explicit intent.
Filter	All mechanisms in place to block from further processing types of information that have been previously determined as irrelevant; a filtering process is necessary to prevent information overload.
Implicit Intent	The internalized collective and individual knowledge, expectations, and beliefs that are presumed upon to guide actions, consciously or otherwise; derives from the extensive knowledge bases people acquire through experience, such as beliefs, values, habits, expectations, and personal styles, in or out of the military.

Inductivism	Philosophical premise that observation is a process of unbiased reception of information in which "facts" manifest themselves in what one observes; implies that perception should be "unbiased," without pre-conceived ideas or theories intruding on the process of gathering information from the environment.
Mental Model	A situational and dynamic mental representation that maps elements of an external system (a problem, situation, or event) and the inter-relationships among those elements onto a conceptual structure; a representation used in planning and decision making in complex tasks.
Situation Model	A mental model that represents the current state of the battlespace; should represent all aspects of the battlespace that affect the validity of the conceptual model.

Distribution list

INTERNAL DISTRIBUTION

DRDC Toronto TR 2003-105

1	-	Director General
1	-	Deputy Director General
1	-	Chief Scientist
6	-	Document Library
1	-	David Bryant (author)
1	-	Ross Pigeau
1	-	Joseph Baranski
1	-	Carol McCann
1	-	Megan Thompson
1	-	David Smith
1	-	Angela Febbraro
1	-	Donna Pickering
1	-	Anne-Rene Blais
1	-	Don McCreary
1	-	LCol Peter Lomasney
1	-	Keith Hendy
1	-	Justin Hollands
1	-	Lochlan Magee
1	-	Stuart Grant
1	-	Peter Kwantes
1	-	Linda Bosse
1	-	Walter Dyck
1	-	John Frim
1	-	Jocelyn Keillor
1	-	Jacqui Crebolder
1	-	Sharon McFadden

EXTERNAL DISTRIBUTION

DRDC Toronto TR 2003-105

1	-	DRD KIM
1	-	DRD KIM (unbound)
1	-	DRDC
3	-	DGOR
4	-	DGJFD
1	-	ST HP
2	-	D ST CCIS
2	-	D ST L
2	-	D ST A
2	-	D ST M
2	-	D MRS
1	-	D MRS 6
1	-	D MRS 6-2
2	-	DAT
2	-	DAD
2	-	DLSC
2	-	DLPS
2	-	D DCEI
1	-	D LCSPM
1	-	DRDB
1	-	DMSS
1	-	DMSS – 6
1	-	DMSS – 8
1	-	DMPPD
1	-	DMPPD 6
1	-	DMPPD 6 –2
1	-	DSTCCIS
1	-	DSTA
1	-	DSTM
1	-	DSTM – 2

2 - DLR

2 - CFEC

2 - DRDC Atlantic

Attn: B. McArthur

B. Chalmers

5 - DRDC Valcartier

Attn: R. Breton

S. Paradis

E. Bosse

J.M.J. Roy

P. Labbe

1 - Canadian Forces Command and Staff College
Toronto
Attn: Commanding Officer

1 - CF Maritime Warfare School
CFB Halifax
Halifax, Nova Scotia
Attn: Commanding Officer