NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

NEWORK CENTRIC WARFARE: A COMMAND AND CONTROL PERSPECTIVE

by

Lim, Soon-Chia

March 2004

Thesis Advisor:	Dan C. Boger
Second Reader:	William G. Kemple

Approved for public release; distribution is unlimited

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, 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, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.			
1. AGENCY USE ONLY	**2. REPORT DATE** March 2004	**3. REPORT TYPE AND DATES COVERED** Master's Thesis	
4. TITLE AND SUBTITLE: Network Centric Warfare: A Command and Control Perspective			**5. FUNDING NUMBERS**
6. AUTHOR(S) Lim, Soon-Chia			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.			**12b. DISTRIBUTION CODE**

13. ABSTRACT (maximum 200 words)

This paper seeks to analyze the command and control issues arising from the advent of NCW.

While information superiority is not a new concept, the blazing speed of advancement in information technologies have brought about dramatic changes to our lifestyles and profound changes in the conduct of modern warfare. This leads to the birth of Network Centric Warfare. NCW offers great opportunities to dramatically enhance combat prowess by establishing shared situational awareness, increasing speed of command, improving systems' lethality and survivability, and enabling greater flexibility through self synchronization. However, these revolutionary changes in NCW do not depend on technology alone. In order to harness the full benefits of NCW, the full span of elements ranging from organization, doctrine, operational concepts to training must co-evolve.

The success of NCW is dependent on aligning the organization's commitment, resources and efforts, fostering a learning and innovative culture, constructing a seamless, robust and secured infostructure, and establishing measurement of effectiveness of C2. The journey to the NCW is not a linear process, but rather a spiral developmental process. Continued evolution and efforts are required to shape and deliver the enhanced combat capability as the apex of maturity of the spiraling cone.

14. SUBJECT TERMS			**15. NUMBER OF PAGES** 105
Network Centric Warfare, NCW, Command and Control, C2.			**16. PRICE CODE**
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

THIS PAGE INTENTIONALLY LEFT BLANK

Approved for public release; distribution is unlimited

NETWORK CENTRIC WARFARE: A COMMAND AND CONTROL PERSPECTIVE

Lim, Soon-Chia
Lieutenant Colonel, Republic of Singapore Air Force
B.Eng., The Victoria University of Manchester (University of Manchester Institute of Science and Technology), 1990

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN INFORMATION TECHNOLOGY MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
March 2004

Author: Lim, Soon-Chia

Approved by: Dan C. Boger
Thesis Advisor

William G. Kemple
Second Reader

Dan C. Boger
Chairman, Department of Information Science

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

This paper seeks to analyze the command and control issues arising from the advent of NCW. It aims to contribute to a practical understanding of the concept and an implementation approach for NCW by attempting to provide an analytical framework, the various options/models, and considerations across the spectrum of NCW issues.

While information superiority is not a new concept, the blazing speed of advancement in information technologies has brought about dramatic changes to our lifestyles and profound changes in the conduct of modern warfare. This led to the birth of Network Centric Warfare (NCW). NCW offers great opportunities to dramatically enhance combat prowess by exploiting shared situational awareness, increased speed of command, improved systems' lethality and survivability, and greater flexibility achieved through self synchronization. However, these revolutionary changes do not depend on technology alone. In order to achieve the full promise of NCW, the entire span of elements ranging from organization, doctrine, and operational concepts to training must co-evolve.

The success of NCW is dependent on aligning the organization's commitment, resources and efforts, fostering a learning and innovative culture, constructing a seamless, robust and secure infostructure, and establishing measures of effectiveness of C2. The journey to NCW is not a linear process, but rather a spiral developmental process. Continued evolution and efforts are required to shape and deliver the enhanced combat capability as the apex of maturity of the spiraling cone.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

I. INTRODUCTION....................1
A. BACKGROUND....................1
1. Technology Advancement....................2
a. Moore's Law....................*2*
b. Law of Transmission Capacity....................*2*
c. Law of Storage....................*2*
d. Metcaltfe's Law....................*3*
2. Expanded Spectrum of Conflict and Changing Threats....................4
a. Expanded Spectrum of Conflict....................*4*
b. Changing Nature of the Battlefield....................*4*
c. The Media Factor....................*5*
B. PURPOSE....................6
C. SCOPE....................7
D. RESEARCH METHODOLOGY....................7
E. CHAPTERS OVERVIEW....................8

II. NETWORK CENTRIC WARFARE (NCW)....................9
A. DEFINITION....................9
B. CONCEPTUAL FRAMEWORK....................10
1. Impetus....................10
2. Means....................10
3. Outcome....................11
C. ATTRIBUTES/CHARACTERISTICS....................11
1. Extensive Connectivity and Interoperability....................11
2. Common and Shared Situational Awareness....................12
3. Co-operative Sensing....................12
4. Collaborative Planning and Execution....................13
5. Compression of Time and Space....................13
D. BENEFITS – ENHANCED COMBAT POWER....................13
1. Decision Superiority....................14~~13~~
2. Dominant Maneuver....................14
3. Precision Engagement....................15
4. Focused Logistics....................17
5. Full Dimensional Protection....................17
E. IMPACT TO COMMAND AND CONTROL....................18

III. COMMAND AND CONTROL ORGANIZATION....................21
A. COMMAND AND CONTROL....................21
B. CURRENT C2 ORGANIZATION....................22
C. NETWORK VERSUS HIERARCHICAL....................22
a. Removing Impediments to Speed....................*23*
b. Workload....................*24*

c. Information Systems *24*
D. CENTRALIZATION VERSUS DECENTRALIZATION 25
1. Decentralization 25
2. Centralization 25
3. The Middle Way 27
a. Over-Centralization *27*
b. Laissez Faire *28*
c. Avoiding Micromanagement *28*
E. ORGANIZATIONAL MODEL 29
1. A Perspective from the A2C2 Program 29
2. A Perspective from Organizational Theory 30
F. SUMMARY 30

IV. C2 PROCESS AND DOCTRINE 33
A. COMMAND AND CONTROL PROCESS 33
1. The OODA Loop 34
2. The Lawson-Moose Cycle 35
3. The HEAT Process 36
B. THE CURRENT APPROACH 37
C. THE EVOLUTION OF C2 PROCESS 38
1. Time Compression 38
2. Collaborative Planning and Execution 39
3. Harnessing Greater Flexibility 41
D. C2 DOCTRINE 42
E. SUMMARY 43

V. C2 INFOSTRUCTURE AND SYSTEMS 45
A. PURPOSE 45
B. INFOSTRUCTURE 46
1. Information Grid 47
2. Tactical Control Grid 47
3. SA (or Situational Awareness) Grid 47
4. Targeting/Engagement Grid 48
C. C2 SYSTEMS 49
D. AN HETEROGENOUS ARCHITECTURAL FRAMEWORK 50
1. Operational Architecture 52
2. Technical Architecture 52
E. OPERATIONALIZATION 54
F. SUMMARY 55

VI. THE ROADMAP TO NCW 57
A. KEY SUCCESS FACTORS 57
1. Organizational Alignment 57
2. A Learning and Innovative Culture 57
3. Entry Fee 58
4. Co-evolutionary Development 58
5. Measures of Effectiveness/Performance (MoE/MoP) 59

6. **Incremental and Evolutionary Approaches 59**

B. **THE ROADMAP 59**

1. **Understanding and Appreciating NCW 59**
2. **Establishing the Infostructure 60**
3. **Organizational Blueprint and Architectural Framework..............61**
4. **Research and Experimentation 63**
5. **Specifying and Measuring Performance...64**

   a. ***Measures of Merit (Alberts et al.,1999)..................................65***

   b. ***Headquarters Effectiveness Assessment Tool*** (Hayes, 1999)..***66***

   c. ***NATO Hierarchy for Metrics*** (Clark, 1999)............................***66***

C. **SUMMARY 68**

VII. **ARCHITECTING NCW 69**

A. **ARCHITECTURE AS AN APPROACH 69**

B. **ARCHITECTURAL CONCEPT AND FRAMEWORK 70**

C. **FoS / PRODUCTION LINE METHODOLOGY...72**

D. **ARCHITECTURAL EVALUATION 74**

E. **SUMMARY 75**

VIII. **CONCLUSION 77**

A. **THE NEW CIRCUS MAXIMUS 77**

B. **C2 CHALLENGES 77**

1. **New and Smarter Ways..77**
2. **Change Management...79**
3. **The Search for the Rosetta Stone 80**

C. **AVOIDING THE PITFALLS...81**

D. **SUMMARY 82**

LIST OF REFERENCES 85

INITIAL DISTRIBUTION LIST 89

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF FIGURES

Figure 1. Conceptual Framework 10

Figure 2. Three Phase Organizational Design Process (From: Kleinman, D.L., Levchuk, G.M., Meirina, C., Pattipati, K.R. 2001. "Design & Analysis of Robust and Adaptive Organization") 30

Figure 3. The OODA Loop (From: Kenneth C. Allard. 1990. *Command, Control and the Common Defense* [New Haven, CT: Yale University Press]) 34

Figure 4. The Lawson-Moose Cycle (From: CAPT Wayne P. Hughes Jr., USN, Retired. 1986. *Fleet Tactics* [Annapolis, MD: Naval Institute Press]) 35

Figure 5. The Headquarters Effectiveness Assessment Tool (HEAT) Process (From: John E. Kirzl. 1999. *Command and Control Evaluation in the Information Age*.) 36

Figure 6. Army's Decision-Making Cycle (From: U.S. Army Filed Manual " The Infantry Battalion". FM7-20) 37

Figure 7. C2 Functional Spheres (From: John E. Kirzl. 1999. "Command and Control Evaluation in the Information Age".) 39

Figure 8. C2 Functional spheres linked by Information (From: John E. Kirzl. 1999. "Command and Control Evaluation in the Information Age".) 40

Figure 9. The Situational Awareness (or Sensor) Grid. (From**:** Stein, Fred P. 2003. "Observations on the Emergence of Network Centric Warfare". Evidence Based Research Inc. <http://www.dodccrp.org/steinncw.htm/>> [29 Oct 2003]) 48

Figure 10. ATAIS Structure (From: Hayes-Roth Frederick. Sep. 2003. "Architecture, Interoperability, and Information Superiority") 52

Figure 11. NIST Enterprise Architecture Model (From: CIO Council. 1999. *Federal Enterprise Architecture Framework*.) 62

Figure 12. Mission Capability Package Process (From: U.S. DoD. July, 2001. *Network Centric Warfare - Report to Congress*.) 64

Figure 13. Hierarchy of Measures of Merit (From: Alberts, D.S., Garstka, J.J. & Stein, F.P. 1999. *Network Centric Warfare: Developing and Leveraging Information Superiority*. 2nd Edition. CCRP.) 65

Figure 14. MORS Hierarchy of Metrics (From: Clark T & Moon T, 1999. "Assessing the Military Worth pf C4ISR Information. 7th International Command and Control Research and Technology Symposium). 67

Figure 15. 1st Level of architecting : Envisionment 70

Figure 16. 2nd Level of architecting: FoS Development – Hybrid Framework 71

Figure 17. Barriers to Information Access (From: Kemple, W and others. 1999. *Building Adaptive Organizations: A Bridge from Basic Research to Operational Exercises*.) 79

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

Table 1. Three-level Architecting Concept..70

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

A. BACKGROUND

Throughout history, military leaders have regarded information superiority as a cornerstone of military success. Even in ancient time, where manhood and heroism were highly upheld, Sun Tze wrote:

> He who has a thorough knowledge of himself and the enemy is bound to win in all battles. He who knows himself but not the enemy, has only a chance of winning. He who knows not himself and the enemy is bound to perish in all battles.

In his book *Command in War*, Martin Van Creveld (Van Creveld, 1985) stipulated that the history of command (and control) consists essentially of an endless quest for certainty – certainty about the state and intentions of the enemy's forces; certainty about the manifold factors that together constitute the environment in which the war is fought, from weather and the terrain to radioactivity and the presence of chemical warfare agents; and, last but definitely not least, certainty about the state, intentions, and activities of one's own forces.

Yet, Network Centric Warfare which is premised upon the attainment of information superiority - the importance of which has long been acknowledged and emphasized – is touted as the next most important RMA in the past 200 years (Cebrowski & Garstka, 1998).

Information Superiority remains the linchpin of military victory. That has not changed. There is essentially no substitute for knowledge, or information superiority. Information superiority can be a force multiplier and the source of combat prowess. What has changed is the convergence of many capability-enabling technologies in an information-driven era coupled with the emergence of new threat scenarios. Together they have dramatically transformed the modern battlefield. This revolution is creating not only quantitative, but also qualitative, changes in our operating environment that will bring about profound changes in the conduct of military operations. (US JCS, 2000)

1. Technology Advancement

The rapid developments and underlying trends in information technologies are coalescing to accelerate and deliver an unprecedented transformation of the environment that we are operating in. These enabling technologies are advancing at a blazing pace which has been generalized into a number of laws:

a. Moore's Law

Prescribed by Gordon E. Moore, then R&D Director at Fairchild Semiconductor in 1965, this law postulates that the performance of computer chips will double approximately every eighteen months. These **advances in the semiconductor fabrication technology**, mainly due to increasing component density, translate to increasingly powerful computers, and at the same time to improved economics in proliferating computer usage, both in terms of cost and size. As an example, relative to the price of labor, processing power has become cheaper by a factor of 5×10^{12} over the last ten years or by a factor of five trillion! (McGray, 2003)

b. Law of Transmission Capacity

This law suggests that the transmission capacity of fiber optic cable will double every nine months (Khoo, 2003). This showcases the **advances in dense wave division multiplexing** which is the key to enabling the significant increase of the internet. This translates into increasingly larger bandwidth available and faster download speeds for users.

c. Law of Storage

The "Law of Storage" forecasts that for a given cost, storage capacity will double every twelve months (Khoo, 2003). This has led, for example, to the ability to have very high-resolution pictures stored in cameras and other portable digital devices.

The above technological advances have brought about the phenomenal proliferation of computers, and fueled the exponential growth of the internet, intranets, and extranets. Combined with high-speed data access (enabled by the low cost laser) and the technologies for high-speed data-networking (hubs and routers), these have liberated computers and systems from many inter-operability constraints to create a network-centric computing platform which has led in turn to a boom in the communities that create, distribute, and exploit information "content" across an extremely heterogeneous global computing environment.

d. Metcaltfe's Law

Named after Robert Metcalfe, inventor of the ethernet protocol and founder of 3Com, it describes the potential benefits brought about by networking technologies. While not about advances in the enabling technologies, Metcalfe's Law has emerged as a central metaphor for the Internet Age. It postulates that although the cost of deploying a network increases linearly with the number of nodes in the network, the potential value of a network increases as a function of the square of the number of nodes that are connected by the network. To first order, it describes the potential number of information interactions that are enabled by a network of "N" nodes. To second order, it provides insight into the fact that the "value" of a network to the users of the network is primarily a function of the interaction between them (Alberts et al., 1999).

These technological developments have revolutionized nearly every aspect of our lives and of the business world. Communications with distant friends no longer depends on postal letter or fax, but rather on quick and almost instantaneous e-mail and networking facilities. These technologies have created orders of magnitude increases in our ability to operate in the information domain, transforming our operation from one of information collection and processing to one of collaborative planning and execution. New internet or e-businesses also bring about new information-based business strategies that aim at locking-out competition and locking-in success premised on increasing instead of diminishing returns.

The military is feeling the impact, too. The technological advances have ushered in an environment where time and space can be effectively compressed. Geographically dispersed forces can cooperate electronically through the distribution of awareness and knowledge in the battlespace. Decision timelines can be compressed with effective communications and networking. These have transformed the problem of warfare from a series of static events to a more continuous one, and portend an ultimate merging of the disparate planning and execution processes into a seamless form of command and control.

2. Expanded Spectrum of Conflict and Changing Threats

The Information Era is changing the battlespace in three fundamental ways, namely, the expansion of the spectrum of conflict, the changing nature of the battlefield, and the 'Media Factor'; referring to the ubiquity of the media.

a. Expanded Spectrum of Conflict

The spectrum of conflict has expanded over the years. During the bi-polar Cold War Era, the world was poised for a conventional war between the two superpowers. The collapse of the Bradenburg gate and the Soviet Union, however, have given rise to localized conflicts and rogue states. These resulted in increased occurrences of operations other than war (OOTW), from humanitarian relief, peace enforcement to most notably, terrorism. Unlike conventional warfare that is pitted between nation states or clans – generally with visible organization and physical boundaries of influence, OOTW can sometimes mean fighting an enemy that is in hiding and yet almost omnipresent. Unlike conventional warfare which is preceded by stages from preparation to declared hostilities, OOTW can happen anywhere anytime. These asymmetrical threats can become even more potent with the increased lethality and accessibility of weapons of mass destruction (WMD). It can be extremely manpower and attention draining for a conventional military force to safeguard against such attacks. Information and correlation of events and trends are thus critical to raising the alarm and compressing the execution time for an effective response. The fact that the form of the enemy is unclear will blur the distinction between domestic and foreign, and civilian and military threats. The boundaries are becoming less distinct and more complex. Information must be available at higher levels of resolution to help in ascertaining the friend and the foe.

b. Changing Nature of the Battlefield

A new form of warfare has also emerged. With today's information being largely stored and transacted in 0 and 1s, information operations or cyberwar, has the potential to totally redefine the nature of warfighting. It will blur the boundaries between civilian and military responsibilities. Information attacks, not necessary at military targets, but also at critical civil/business institutions can cause havoc by detrimentally undermining a country's interests without even dropping a bomb! Essentially, the nature of war has become more diverse and sophisticated. Important safeguards must be in-place to protect against such vulnerabilities and prevent such occurrences.

c. The Media Factor

The ubiquity of the western media has brought about two effects. The first is an increase in the tempo of operations, and the second is the loss of secrecy by bringing each and every event under the intense scrutiny of the public.

Exploiting the advances in information technologies, the media has harnessed the same benefits of instantaneous communications and greater bandwidth as the military. This has enabled them to provide regular and timely updates of the battle situation to anyone. Instantaneous imagery is no longer held just within the warfighting forces. It was said that even warring forces watched TV programs for intelligence information. In fact, deposition of combat forces may no longer be kept secret for long. Military decision makers are pressured to assimilate information fast, decide fast, and move and act even faster to achieve tactical surprise and to safeguard against the media compromising the required secrecy.

Today's war is no longer fought just in the deep jungles or the vast deserts, it is also enacted via the TV right in the living rooms of millions of people around the world. Under intense public scrutiny, a single event can be exploited way out of proportion to its significance. So the saying goes, "Bad news is good news". Military decision makers have to rethink the allocation of targets and the possible extent of collateral damage, which might invite international outcry once the gory images were published. Military combatants must be aware of the media to make sure that it does not take on a route of its own to denounce the war and dictate its outcome. Increasingly, the military will be judged not only by whether or not a mission was accomplished, but also whether or not it accomplished the mission with an appropriate level of force, or the minimum level required to achieve the effect. Traditional military operations, conceived and conducted under the doctrine of overwhelming force, may prove to have adverse political consequences. The military will have to leverage the new information toolkit to achieve more stealthy maneuvers, while at the same time, managing public expectations on what it can and cannot achieve or avoid.

With the end of the “Cold War”, defense budgets around the world were generally on a visible decline in anticipation of an era of peace. Between 1989 and 1999, world defense expenditure dropped by some 35%. Defense budgets of developed countries suffered the most, shrinking some 48% over the same period (U.S. DVBC, 2002). By early 1989, the trend towards more relaxed relations between the United States and the Soviet Union was firmly established and most NATO countries had started reducing their military forces. However, the hope of an era of peace soon dissipated after the 9/11 event which portended the emergence of terrorism. A period of ‘troubled peace’ has been ushered in, giving rise to new perceptions of threats. But most of the forces have already been stripped down. Also, given the economic reality, few governments can increase defense spending and the force structure with impunity. New ways of warfare must be explored to equip the nation with greater combat power. This impetus also gives rise to the rapid refocus onto NCW.

All in all, the technological advances and the changes in the battlespace conceived the birth of NCW. The military-economic developments/realities expedited embracing new information age warfare. These changes have fundamentally transformed our attitude towards gathering of information, tolerance of uncertainty, acceptance of the fog of war, and the landscape and environment of modern battlespace. These have very fundamental implications to the conduct of warfare, and in fact, go to the core of how command and control, and its various constituent domains, can be best constructed and optimized.

B. PURPOSE

This thesis analyses the command and control issues arising from the advent of NCW, the why and how to organize, operate, construct and optimize the various domains of command and control in order to achieve the promised ‘order of magnitude’ increase in combat or warfighting capabilities.

While many have written on the subject of NCW, few have gone beyond an exciting yet obscure vision of an end-state and the journey towards it. In fact, more recent writings seem to be moving even further into conceptual and theoretical aspects, and arguably, little tangible progress has been made. This thesis, hence, is not intended as another theoretical disquisition on the subject, but rather the principal goal of this thesis is to attempt to provide an analytical framework for the military decision-maker and the various options/models, or considerations in understanding and implementing the concept.

This study aims to contribute to a practical understanding of the concept and an approach towards NCW. Such understanding is critical in shaping the force structure and operational doctrine of future organizations, and their warfighting capabilities.

C. SCOPE

The thesis seeks to answer a series of command and control questions related to NCW:

What is the NCW concept?

How should we organize to take advantage of NCW?

How should C2 processes evolve?

How should the various domains of C2 be constructed to better align with NCW?

What is the roadmap for implementing NCW?

This thesis will be based on literature research and analysis on the topic of Network Centric Warfare (NCW). In addition, findings from experimental exercises such as Global ’98 will also be used as appropriate. Its main focus will be on the command and control issues. While the research may be based on the US experience and model, the conclusion drawn is intended for military organizations in a more general context.

As the author is no proclaimed expert or authority in the subject matter, the study will not have the definitive solution for NCW implementation or indoctrination. Nevertheless, in attempting to provide more practical value, this thesis will strive to narrow down the options or implementation models. Where not practicable, however, the considerations affecting decision will be explicated instead.

D. RESEARCH METHODOLOGY

The thesis starts by examining the changing battlespace landscape and the impetus of NCW. It will review the definition and concept of NCW explicated in current literature, and then attempt to analyze the implications at hand and challenges that lie ahead. On the command and control aspect, analysis will also be based on organizational theory, as well as results from the A2C2 (Adaptive Architectures for Command and Control) research program. The thesis will conclude with a proposed roadmap to embrace NCW.

E. CHAPTERS OVERVIEW

Chapter 1 - Introduction. This chapter explains the background and factors that led to the conception and birth of the NCW concept.

Chapter II – Network Centric Warfare (NCW). This chapter seeks the definition of NCW, and establishes a conceptual framework for analysis, comprising impetus, means and outcome. It provides a glimpse on the attributes of NCW and its potential benefits supported by findings from experimental exercises.

Chapter III – Command and Control Organization. This chapter dwells on the organizational structure of command and control, explicating the contentions between network vis-à-vis hierarchy, and centralization vis-à-vis decentralization. It draws organizational design models and guidelines from the Adaptive Architectures for Command and Control (A2C2) research program, as well as from a review of organizational theory.

Chapter IV – C2 Doctrine and Process. This chapter deliberates the doctrinal impact NCW. It revisits the various cyclical models of the C2 process, and explores the notion of self-synchronization and continuity in the C2 process.

Chapter V – C2 Infostructure and Systems. The networking infrastructure and the information systems are the supporting means and key enabler for the pursuit of NCW. This chapters looks at the issues concerning the establishment and design of the information grids and the information systems to support the new warfare concept in an information era.

Chapter VI – The roadmap towards NCW. This chapter lists the success factors and outlines the key steps for NCW implementation. It is noted that the roadmap is not a linear process but rather a cyclical, or spiral journey.

Chapter VII – Conclusion. This chapter presents some of the daunting challenges facing NCW, and also highlights some of the potential pitfalls.

II. NETWORK CENTRIC WARFARE (NCW)

A. DEFINITION

A review of the literature yields a number of definitions for Network Centric Warfare. The more representative ones are listed below:

1. “Network Centric Warfare (NCW) is an **information superiority-enabled concept** of operations that generates increased combat power by **networking** sensors, decision makers, and shooters to achieve shared awareness, increased speed of command, higher tempo of operations, greater lethality, increased survivability, and a degree of self-synchronization. In essence, NCW translates information superiority into combat power by effectively linking knowledge entities in the battlespace.” (Logan, 2003).

2. “Network-Centric Warfare derives its power from the strong **networking** of a well-informed but geographically dispersed force. The enabling elements are a high-performance information grid, access to all appropriate information sources, weapons reach and maneuver with precision and speed of response, value-adding command-and-control (C2) processes--to include high-speed automated assignment of resources to need--and integrated sensor grids closely coupled in time to shooters and C2 processes. Network-centric warfare is applicable to all levels of warfare and contributes to the coalescence of strategy, operations, and tactics. It is transparent to mission, force size and composition, and geography.” (Cebrowski, 1998).

3. “A Warfighting Concept that enables a Network Centric Force to significantly increase combat power by achieving increased awareness, shared awareness, degree of interoperability, survivability, lethality, responsiveness, operational tempo, and ability to self-synchronize”. (Alberts & Garstka, Dec 1999).

Three elements are clearly distinctive from the above definitions. These are the Impetus of NCW, the Means to establish it, and the Outcome/Benefits it aims to achieve, i.e., Enhanced Combat Capabilities.

B. CONCEPTUAL FRAMEWORK

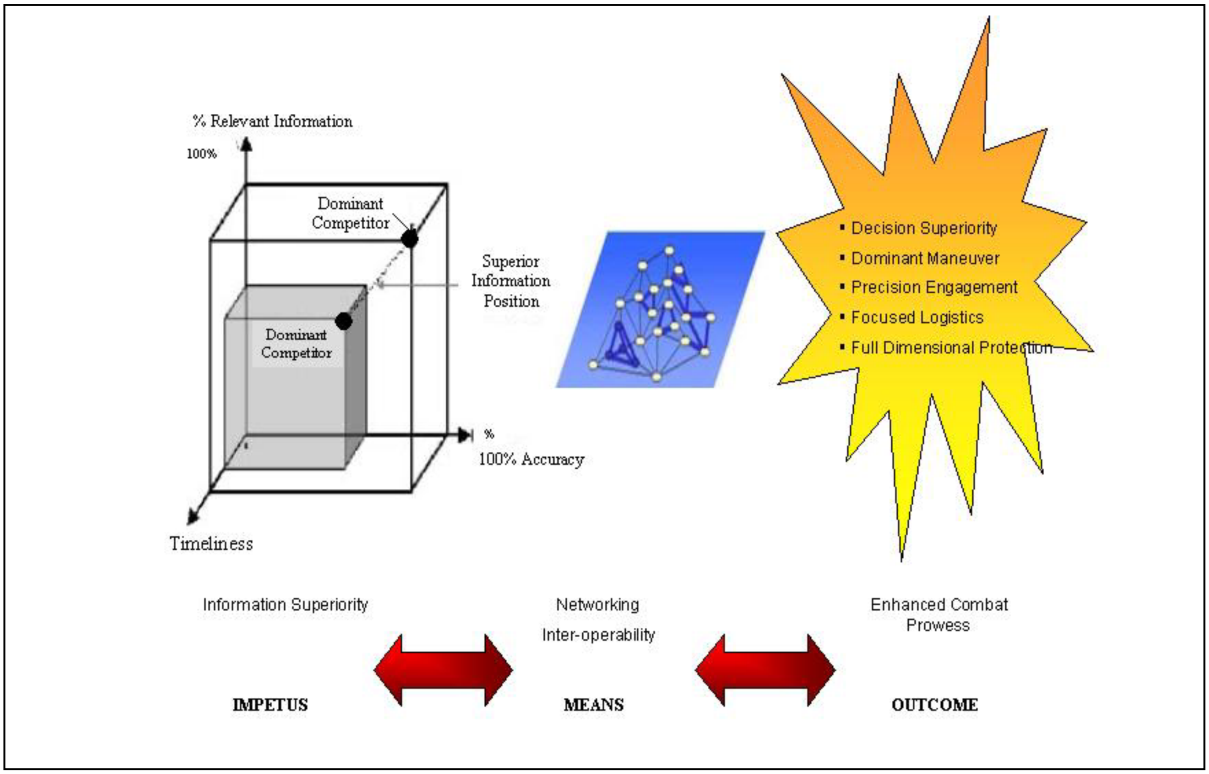

Figure 1. Conceptual Framework

1. Impetus

NCW is premised on the concept of Information Superiority. Information has the three key dimensions of relevance, accuracy, and timeliness (Alberts et al., 1999). See Fig. 1. A position of information superiority is attained when the information available/created establishes the player in a dominant vantage as compared to its competitor, whereby the player is superior in no less than one key dimension and at least equal in the other dimensions vis-à-vis its competitor. Such an information superior position can be exploited to derive competitive advantage. Taking an analogy from the business world, the information superior position can be exploited to lock-in success/victory, and lock-out competition/threats. This is the impetus of NCW.

2. Means

What then are the means to establish the higher vantage point in the information domain? Essentially, the enhanced richness and reach of the information is established by access to all appropriate information sources, primarily among all the warfighting enterprises, despite geographical dispersion. Three primary parties or roles need to be connected, namely, sensors, decision makers and shooters/weapon systems. The technicality of this infostructure or domain is further elaborated in subsequent chapters. For now, it suffices to note that the accesses can be enabled through high performance information grids (such as integrated sensor grid) to closely couple and disseminate information (such as situation awareness) among the parties involved. These networks aim to support the distribution of common situation awareness, and facilitate collaborative planning and execution.

3. Outcome

It is important to note that technology is but one of the key elements of NCW. Successful transformation from platform-centric to a net-centric force not only entails the co-evolution of technology, organization, and doctrine, but also a basic change in the mindset. With a synergistic conglomeration of the various NCW elements, enhanced combat capabilities could be delivered in the following areas:

a. Decision Superiority

b. Dominant Maneuver

c. Precision Engagement

d. Focused Logistics

e. Full Dimensional Protection

The critical question is the big HOW? In another words, how to translate the means, that is, information networking, to war-winning, information dominating NCW enhanced combat power. The subsequent chapters will attempt to answer the question of HOW, but the remainder of this chapter will elaborate on the attributes and characteristics of NCW, and provide a glimpse of the enhanced combat capabilities that could be harnessed.

C. ATTRIBUTES/CHARACTERISTICS

NCW may be characterized by:

1. Extensive Connectivity and Interoperability

Clearly, the first and foremost characteristic that would come to mind is the extensive connectivity in the NCW environment. A robust, high-performance infostructure that provides all elements of the warfighting enterprise with access to high-quality information services will be established. The number of information sources and combat nodes to integrate will be an order of magnitude more than in the past. Implicit, though it cannot be taken for granted, is a greater degree of inter-operability, and thus co-operation, among the warfighters.

2. Common and Shared Situational Awareness

Traditionally, the battlespace in the theatre of operations is often segmented and the responsibilities of updating the awareness within the localized area is parsed to different combat entities. Their respective situational pictures are communicated through voice or electronic pointers, collated and presented on large display boards manually. This has resulted in significant barriers and delays in pulling together a complete picture for the entire Area of Operation (AOR). NCW, enabled by the increased network bandwidth, will see a proliferation of common operating pictures (COPs) transcending through and distributed across the military hierarchies, from the strategic level to the lower echelons. These COPs will be collated by a central agency or key nodes through sensor and systems input spanning the operating theatre, before being pushed down to the lower echelons. Notably, though, at the lower echelon, the coverage of the COP may be within a much smaller geographical span - hence the notion of the Common Relevant Operating Picture (CROP) - as compared to the "Big Picture" at the operational/strategic levels.

A common and shared situational awareness is the direct result of the distribution of these COPs, which are usually supplemented with peripheral operational information. This shared awareness reduces the fog of war and increases the certainty and quality of decision-making.

3. Co-operative Sensing

In platform-centric combat such as in air-to-air engagement, the shooter would usually have its organic sensors for the purpose of target acquisition and fire control. In network-centric combat, however, the sensor and shooter may be decoupled as a result of co-operative sensing. Premised on a high performance engagement grid, the shooter no longer needs to depend solely on its organic sensors. It can grasp data from the engagement grid and use it for target sorting and engagement. Similarly, a station or even a command center, no longer just depends on its local sensors. Rather, it collates information from sensors and systems throughout the operating theatre to form a comprehensive situational picture of the battlespace.

4. Collaborative Planning and Execution

Traditionally, planning is done centrally or at one locality. Increasingly though, collaborative tools are available to aid planners by soliciting specialist feedback directly from the combatant without relying just on faxed reports. While sectorised operations may have been the *modus operandi* previously, more collaborative execution can be exercised without strict adherence to operating boundaries given shared and enhanced situational awareness of each others' activity. In that sense, arbitration or optimization at the next higher level may be less required, and may be left to the lower echelons to sort out among themselves. This is referred to as the self-synchronization ability, or "the ability of a well-informed force to organize and synchronize complex warfare activities from the bottom up" (Cebrowski, 1998).

5. Compression of Time and Space

The instantaneous nature of communications means that time and space for information flow are being compressed. No longer, will there be a need to send copies of a mission order through fax (which could take up to hours). In fact, combatants can be sent out to the battlespace with initial missions, and the higher resolution details of targets, for example, can be followed up, thereby dramatically compressing the entire mission cycle. Similarly, geographically dispersed forces are no longer handicapped by the spatial distance apart. Networking has brought a wider geographical area under the span of co-operation/control of any single combat entity. Modern communication and networking technologies have eradicated undue transit delays and as a result, increase the operational tempo and responsiveness of modern warfare.

D. BENEFITS – ENHANCED COMBAT POWER

NCW is touted to deliver greatly enhanced combat prowess. The following paragraphs provide a glimpse of these benefits supported by a consolidation of preliminary experimental and exercise evidences.

1. Decision Superiority

Decision superiority is a direct benefit of information superiority that provides military forces the competitive combat edge. However, it is important to note that availability of information does not automatically translate into decision superiority, it must be filtered through warfighter’s experience, knowledge, training and judgment, honed by organizational and doctrinal adaptation, relevant training and experience, and facilitated by the proper command and control mechanisms. Also, decision superiority does not refer only to the capability of the commanders to make decisions, but rather to the warfighting force to make decisions as a whole, that is, including, valued-added from combatants and supporting staff at the various echelons, and the efficiency of the associated processes.

JTIDS Operational Special Project demonstrated the increased mission effectiveness as a result of decision superiority. In an experiment which compared the operational performance of Air Force F-15Cs performing counter air operations with and without data links, the Air Force found that the kill ratio increased by over 100 percent with network-centric operations. This increased combat power is a result of the significantly enhanced battlespace awareness that was provided to the pilots operating with tactical data links. Components of awareness included weapons loading of the blue force, real-time position of the blue and red force, and status of blue engagements. The net result was a significantly improved decision-making capability in orienting, sorting and engaging targets (US DoD, 2001). Findings from recent All Service Combat Identification Evaluation Team (ASCIET) Exercises reinforced these findings. (Alberts et al., 1999)

2. Dominant Maneuver

Dominant maneuver is the ability of Joint forces to gain positional advantage with decisive speed and overwhelming operational tempo in the achievement of assigned military tasks (US JCS, 2000). NCW enables dominant maneuver through adaptive and concurrent planning, co-ordination of geographically dispersed units, gathering of timely feedback on the status, location, and activities of subordinate units, and the anticipation of the course of events leading to mission accomplishment. These allow the efficient scaling and massing of force or forces that were widely dispersed, as well as massing of the effects of their fire, and thereby achieve the objective of dominant maneuver.

Operational Gains of Digitization '89 showed the benefits of reducing the time taken for planning, responding to a call for fire, mounting an attack, and moving to contact in delivering the impact of dominant maneuver. The U.S. Army's Division XXI AWE produced dramatic results by killing over twice the enemy in half the time at over three times the battlespace with 25 percent fewer combat platforms as a result of successful employment of information age technology in dominant maneuver (Bond, 1998).

3. Precision Engagement

Precision Engagement is the ability of Joint forces to locate, survey, discern, and track objectives or targets; select, organize, and use the correct systems; generate desired effects; assess results; and reengage with decisive speed and overwhelming operational tempo as required, throughout the full range of military operations (US JCS, 2000).

NCW enhances forces' ability to engage targets with greater precision, and at reduced vulnerability, through improved situational awareness and co-operative sensing. Lethality of combat power is a function of the amount of fire power, its reach and its precision. NCW enables closer co-ordination and co-operation of fire power. Through a co-operative network of sensors that provides high performance, engagement quality information, the weapon reach and precision of the shooting platform can be significantly enhanced.

In platform-centric operations, combat aircraft frequently depend on their organic sensor for weapon delivery and even early warning. However, especially in a hostile area, emitting the organic sensor is a double-edged sword. While it improves situational awareness and guides weapon delivery, it also gives up the secrecy of one's location and the element of tactical surprise. This renders the aircraft susceptible to enemy counter response, and hence reduces its survivability. However, in NCW, the combat plane can depend on other sensors, staying stealthy for as long as possible, thus increasing the element of surprise and hence mission effectiveness, while reducing its vulnerability. Such scenarios are readily observed in any of the air battle experiments such as the attack operations with tactical data links in the JTIDS Operational Special Project mentioned above.

New operational concepts such as CEC (Co-operative Engagement Concept) also bring about extensions in the engagement envelopes, and even beyond line-of-sight engagement. The CEC concept enables incoming targets to be engaged in depth with multiple shooters and increased probability of kill. At the same time, survivability of the shooting platform is enhanced by using engagement quality information generated by sensors not organic to the shooting platform, and perhaps beyond line-of-sight of its adversary. In comparison, combat power in platform-centric operations is often marginalized by the inability of the platform to generate engagement quality awareness at ranges greater than or equal to the maximum weapon employment envelope.

The U.S. Navy Fleet Battle Experiment series also provided proof of precision engagement in an NCW environment. (Alberts et al., 1999). This is an annual Joint and combined exercise sponsored by Combined Forces Command, Korea. During Fleet Battle Experiment (FBE) Delta, conducted in October 1998 in conjunction with Exercise Foal Eagle '98, the network-centric concepts experimented with within FBE Delta linked Army and Navy sensors and shooters in unprecedented ways. For example, in the Counter SOF Mission, the seemingly intractable problem of countering hundreds of North Korean special operations boats was dealt with on a timeline previously not thought possible. The application of network-centric concepts enabled Army helicopters, P-3s, LAMPS, AC-130s, and land- and carrier-based aircraft units to share a common operational picture and synchronize their efforts from the bottom up. This self-synchronization demonstrated the capability for leakers to be reduced by an order of magnitude and the operational mission to be accomplished in half the time required, compared to traditional platform-centric operations.

During Operation Deliberate Force in Bosnia between August-September 1995, NATO aircrews flew 3,515 sorties of which over 60 percent were flown by shooters. Aircrews successfully attacked over 97 percent of the targets and destroyed or inflicted serious damage on more than 80 percent of them. The target set, which consisted of over 338 aim points within 48 complexes, was painstakingly selected, checked, and rechecked to virtually eliminate risk to civilian life and property. During the entire operation, only a single aircraft, a French Mirage 2000K, was shot down (Tirpak, 1987). Mission success was made possible by timely and accurate information, such as status and disposition of own and adversary forces, which manifested in the increased precision and lethality, reduced collateral damage, and minimal losses.

4. Focused Logistics

Focused Logistics is the ability to provide the Joint force the right personnel, equipment, and supplies in the right place, at the right time, and in the right quantity, across the full range of military operations (US JCS, 2000). NCW realizes this capability through a real-time, web-based information system providing total asset visibility as part of a common relevant operational picture, effectively linking the operator and logistician across Services and support agencies.

The U.S. Navy Fleet Battle Experiment series provided proof of the enormous potential of such logistics self-synchronization in an NCW environment. (Alberts et al., 1999). NCW enables a mechanism for pushing logistics in anticipation of need. For example, one can easily envision a situation in ground operations where near real time information on consumption of fuel and ammunition in weapons platforms (e.g., M1A2 Tanks, M2 Bradley Fighting Vehicles) combined with an agreed-to rule set could significantly improve logistical support. In fact, information on fuel consumption and ordnance expenditure is currently collected in real time with sensors embedded in F-18 aircraft.

5. Full Dimensional Protection

Full Dimensional Protection is the ability of the Joint force to protect its personnel and other assets required to decisively execute assigned tasks (US JCS, 2000). Full dimensional protection is achieved through the tailored selection and application of multilayered active and passive measures, within the domains of air, land, sea, space, and information across the range of military operations with an acceptable level of risk.

During Fleet Battle Experiment Delta (Alberts et al., 1999), land-based fire-finder radars and sea-based AEGIS radars were integrated into an experimental sensor network. This sensor network provided the ground component commander with significantly enhanced battlespace awareness to support the prosecution of the counter fire mission.

This increased awareness also increases survivability by enabling a pilot to select a route that exploits terrain masking and presents a reduced signature to known air defense radars.

As the ranges of our sensors and weapons increase and our ability to move information rapidly improves, we are no longer geographically constrained. Hence, in order to generate a concentrated effect, it is no longer necessary to concentrate forces. This allows us to reduce our battlespace footprint, which in turn reduces risk because we avoid presenting the enemy with attractive, high-value targets. It also expands the concept of maneuver by reducing the need for the transportation or movement of physical objects, a very time-consuming and expensive task.

In Expeditionary Force Experiment '98, split-base operations were tried and demonstrated the potential to both decrease the time required to initiate air operations and free up transport aircraft to move combat capability into theatre. Notably, such dispersion of assets provides not only a smaller footprint, but also reduced vulnerability of 'putting all eggs in one basket'. (Horner, 1998)

In summary, the overall effect of superior information is creating more teeth and less tail. Forces can be deployed with a smaller logistics trail, and hence a less conspicuous footprint. However, there is also more teeth in NCW forces. The entire network of forces could be fighting as a whole, not as single platforms or just regiments of troops, bringing enormous fire power to bear. Force multiplying benefits could be achieved as a result of greater inter-operability, co-operation and battlefield knowledge. Reduced vulnerability is possible with heightened awareness, and improved responsiveness to avoid risk/dangers. The lethality of fire power is increased through increased precision and extended reach as a result of the collaborative effort among forces and the sensor network. All these add to the greater combat prowess to be attained in NCW.

E. IMPACT TO COMMAND AND CONTROL

The potential benefits of shared and increased battlespace awareness, and a compressed and responsive decision cycle have fundamental implications to warfare doctrine. It is more than just injecting information technology in the form of information infrastructure or infostructure. There are many issues that we need to grapple with, from rethinking the organizational configuration, doctrinal principles, and concept of operations to the implementation challenges of the various domains within command and control. The many factors cannot be analyzed in isolation. Each of these factors serves to stimulate a series of interrelated changes in others, and must be studied as a result of their co-evolution.

THIS PAGE INTENTIONALLY LEFT BLANK

III. COMMAND AND CONTROL ORGANIZATION

A. COMMAND AND CONTROL

Command and control is asserting increasing importance with the advent of NCW. In the platform-centric years of warfighting, command and control has always been in the backstage, in the supporting role. The supersonic missiles, the high performance, new generation fighter aircraft, the stealthy frigates have been the main focuses, in part to showcase their combat prowess for the purpose of deterrence. However, over the years, command and control is increasingly in the limelight. The growing complexity and needed investment in C2 have grown exponentially. Its central role in maximizing combat effectiveness and force multiplying benefits in an networked environment have rendered C2 a critical component in tomorrow's warfare.

As defined by the *Department of Defense (DOD) Dictionary of Military and Associated Terms*:, Command and control is " the exercise of authority and direction by a properly designated commander over assigned forces in the accomplishment of the mission." (Joint Pub 1-02, 1998).

In essence, the main goal of command and control (C2) is to promote unity of efforts among all elements of a force so as to execute a mission most effectively and efficiently, and with least casualties. This lies not only in the ability of a commander, but also his entire control apparatus at all levels, to make the most out of the situation.

The advent of NCW thus has great impact to command and control organization as it entails a rethink of today's C2 organizations, doctrine, and processes, among others. One thing is certain, the current hierarchical C2 structure existing in most militaries today ought to be revisited. A rethink of how best to organize the command and control structure and activities is necessary to address the advances in the technological developments and to exploit maximum advantage of the emerging concept of NCW.

The purpose of this chapter is to highlight the key issues and decision considerations concerning C2 organization in an NCW environment. While it would not be possible to propose the ideal C2 organization for NCW, at least not at this moment, this chapter suggests some considerations towards achieving an optimized C2 structure, and the pitfalls to avoid. It will also touch upon the robust and adaptive organizational model developed under the Adaptive Architectures for Command and Control (A2C2) Research program, as well as a perspective from Organizational Theory.

B. CURRENT C2 ORGANIZATION

Ever since the Levee en Masses, the hierarchy approach of the Napoleonic model (*corps-division-brigade-regiment-battalion-company-platoon*) has been the mainstay of today's military organization, so much so that this type of organization has become the de-facto operational command structure. Usually helmed by a flag or general officer, and then branched into service or functional components, a typical Joint force C2 setup comprises several levels, from the decision-maker, planning, to the execution. This traditional structure is borne out of three key factors. First, the growing size, complexity and specialization of military forces require a robust arrangement to conduct and control its activities. Second, human limitation in the span of control. Based on human factors studies, a rough guide for an acceptable span of control is about 5 plus or minus 2 (Alberts et al., 1999), considering the number of entities a human individual could effectively manage. This relatively small span of control has resulted in the multi-layered structure of a large military organization. Third, the safeguarding of information secrecy. In order to preserve the element of surprise and safeguard secret information, the multi-layered structure serves as a convenient vehicle to compartmentalize information on a need-to-know basis for each echelon. In the US Air Force, for example, C2 and planning tend to be centralized, as the complete information/picture, at least at the operational level, is consolidated at the central location. This was aimed to ensure better optimization of forces and efforts across the larger span of forces. Execution is generally decentralized though, to the local commander for expediency, and being the one with the best localized tactical picture.

C. NETWORK VERSUS HIERARCHICAL

A hierarchical structure is inherently incompatible with a network centric environment. The processes of a netted force operating in a network centric environment are intuitively at odds with the rigid and tightly controlled nature of military hierarchy. A key advantage of a networked community is the instantaneous and simultaneous dissemination of information to all the combat entities. Clearly, the layering and dependence on serial interchanges inherent in an hierarchical organization can impede the speed of command and slow down the operational tempo. Yet, the essence of the pyramidal command structure and line of responsibility and accountability must be maintained for the purpose of command and control, rather than left to a *laissez faire* state of affairs.

A balance must be struck between the rigid, yet assuring, hierarchical structure and the laissez faire approach that promotes freedom of interaction. As a result of networking, the hierarchical organization may become flatter. The flatter organization is aimed at promoting express channels of communications while not diluting the essence of command and control in the military organization. It frees up information flow from the chain of command to increase speed of command so as to lock out adversarial options and achieve option dominance, while continuing to orchestrate and optimize resources at a higher level.

A new approach to effectively flatten hierarchies is needed. Streamlining the operational command chain alone to achieve a flatter structure does not suffice. Unlike previously where our organization's effectiveness and efficiency is enhanced through trimming down the size of an organization, the new approach must be more wholesome. The resulting organization created must be a co-evolution of a number of inextricably linked factors. These factors include,

a. Removing Impediments to Speed

Lessons of fledging Information Age organizations that restricted information flow to the hierarchy has shown that such rigidity is a losing strategy. (Pascale, 1998). It makes little sense to devote the scarce resources to restrict information to the extent we had in the past, while trying to achieve the exact opposite. Rather than restrict all information, and provide only the absolute necessity to the lower echelons, the rationalization of information filtering or compartmentalization must take a new perspective. In the spirit of free information flow and interaction, all information must be permitted other than those that must be safeguarded to protect secrecy of sources, plans and actions.

b. Workload

With the proliferation of COPs, C2 nodes at the various echelons gain enhanced awareness which is translated into better battlespace knowledge of the situation and self-synchronization. These lead to less need for frequent co-ordination and collation of situation awareness or picture, which constitutes a major part of the workload. However, it is also conceivable that removing intermediate echelons may increase workload at the various levels as a result of increased command responsibility. The span of control with respect to the workload and the systems available to help each node manage information must be considered. Alternatively, novel methods to manage the overwhelming information can be experimented with to control the workload. One such method is the use of 'Knowledge Managers'.

The concept of "Knowledge Managers' was employed in Global Wargame '99. The "Knowledge Managers" ensured players could prioritize, analyze, display, and disseminate only what was required by the senior commander. It helped the senior commander to better grasp the deluge of information accessible at his fingers tips, and alleviate the tendency, as Barnett says, to become "control freaks". (Barnett, 1999). Without these Knowledge Managers, the resultant information saturation might cause inaction among the participants.

c. Information Systems

The information systems available are critical to the structure of the organization, and in part determine the workload at each node. The streamlining and freeing up of the information flows must be done hand-in-hand with the introduction of information and communications systems. Collaborative tools may ease up communication problems and facilitate collaborative processes. Smart knowledge programs may allow the end-user to sort, pull and push information at the ease of their finger tips, enhance productivity and minimize the negative effects of the plethora of information. Equally important is the appropriate and optimal usage of these systems. One thing is getting the information system installed, another is to fully utilize them. It is important for people not to continue to operate and communicate in the old ways which may such sub-optimize the new systems and hence not derive the full benefits that should be derived.

D. CENTRALIZATION VERSUS DECENTRALIZATION

The result of the proliferation of COP is greatly enhanced and shared situational awareness laterally and vertically across the command and control structure. This reduces the fog of war and minimizes discrepancies in situational awareness across different echelons and laterally among the combat entities. The boundary of strategic, operational and tactical domains is blurred as a result. On one hand, this allows the central command to assert greater control, while on the other hand, it enables greater autonomy of the lower echelons on the premise of better awareness. Therein lies the main contention of organization of command and control in a NCW environment.

1. Decentralization

The key merits of decentralization are speed of command and empowerment of warfighters. Proponents of decentralization argue that "the key to NCW is to generate such high tempo that the high level commander would be incapable of conducting any kind of traditional planning process fast enough to keep up" (Zachery, 2000). This speed could only be achieved through the autonomy of the lower echelons. With better awareness, these lower echelon units can self-synchronize towards mission objective and value–add with initiative, without top-down spoon–feeding directives. These save precious time, and eradicate the tedious and detailed planning requirements at the higher level.

In the future, tactical level commanders will have a better understanding of both the big picture and the local situation. Some proponents of decentralization go as far as saying that the resulting self-synchronization ability would allow so much greater autonomy and empowerment of the combat entities that little planning would be required at the higher command. Therein lies the concerns that command and control may deteriorate into laissez faire, thus disintegrating rather the integrating the war efforts.

2. Centralization

The premise of centralization lies in central orchestration being necessary to achieve maximum optimization of resources and efforts. "The likelihood that greater experience and knowledge will reside at higher command echelons would seem to argue for centralizing decision making and control to the fullest extent allowed by communication capacity". (Fitzsimonds,1998). Taking into consideration the CNN factor, this proposition is even more palpable. In this day and age of instant media imagery, international law considerations, and crucial public opinion, leaders like General Clark have argued that every tactical action has strategic implications (Clark, 2001). The unintentional bombing of the Chinese Embassy during Operation Allied Force is a classic case of a tactical action directly affecting the national-strategic level of war. Therefore, the belief is that senior leaders need to keep close control of tactical operations to ensure achievement of strategic objectives. Some proponents even go as far as saying that maintaining a centralized command and centralized execution structure eradicates the need for clear commander's intent because the tactical level will always be in contact with the operational and strategic leadership. Therein lies the concerns of centralization.

This concern arises when centralization is taken to the extreme, breaking down the job responsibility across the strategic, operational and tactical level. First, higher level commanders may not be the best qualified to manage the systems at the tactical levels. The experts are the individuals who have the proper training prior to and during deployment. Second, in seeking to meddle with the lower level decisions, commanders are wasting their valuable time, weakening the decision making skills of subordinates, and setting a poor precedent for future operations. Bigger issues that should be of their concern may be left unattended. Third, is the temptation and problems of micromanagement. The heightened situational awareness of strategic leaders, beneficial in many ways, has tempted them to direct operations at the lower levels of war by micromanaging tactical operations. Direct operational involvement by the highest levels of national command structure has historical precedent in the Falklands War and Operation Allied Force (Kosovo), among others. However, it has been observed that a highly centralized command and control structure stifles initiative. In a report to Congress on the Iraqi command and control system it was reported that "A rigid top down C2 system" resulted in "a reluctance of Iraqi commanders to exercise initiative." (Keeter, 2003) If the current trend of micromanagement in the political-military domain continues unchecked, a generation of leaders who are incapable of making independent decisions may be developed.

3. The Middle Way

Both views of NCW seem to characterize command and control in network centric system as an either/or proposition – centralized or decentralized, when in fact both methods of C2 will likely be accommodated. Joint Vision 2010 addresses this potential:

> It is important to acknowledge the merit of argument in both side (centralization vis-à-vis decentralization), and explore the balance through continuous experimentation and …. , and of course, situational.

The key to successful command and control is to maximize its benefits while eradicating the potential pitfalls. The modus operandi of the various services shows that indeed the degree of centralization (of command) and de-centralization (of execution) is very much dependent on the scenario and nature of the operations. NCW has increased the span of our options, increased empowerment or autonomy at one end, and greater central oversight at the other end. Command and control should thus remain flexible and adaptive, and the merits of either be determined judiciously based on improving overall battle orchestration, resource optimization, the speed of command and combat effectiveness of empowerment, while minimizing the ill effects of micromanagement. The followings list some potential pitfalls that we must safeguard ourselves against:

a. Over-Centralization

To ensure that network centric systems do not lead to overly centralized command structures, a three-pronged approach may be taken. (Schroeder, 2001). First, organizations must be structured to handle the amount of information that will be received. Exercises provide the practical experience to command network centric systems and allow the commander and his staff to become comfortable and familiar with emerging technology. This familiarity reinforces each member's role in the organization and breeds the trust of his commander that he will be able to carry out his duties. The second prong of the effort rests with doctrine. Doctrine must first recognize that the operational commander will have more situational awareness of the battlefield than ever before. It must also recognize that the shooters and sensors in the field still remain the most qualified and best trained to carry out the mission. Doctrine for C2 under NCW must define the role and limits of control of each actor (decision maker, shooter and sensor). With defined roles, each actor is free to operate and accomplish their specific tasks for which they were trained. The third and final effort rests in effecting change in the human behavior of the commander and is linked inextricably to the first two points. Before a commander willingly delegates control to his subordinates, he must be comfortable with the new technology and volumes of information. Personality will always play a major role in how a commander elects to command but this can be shaped through training and exercises to work more efficiently in network-centric systems.

b. Laissez Faire

While enhanced awareness will allow greater autonomy and empowerment at the lower echelons, it does not replace the need for a good understanding of the commander's intent. While some proponents of de-centralization argued that the enabler of increased speed of command is self-synchronization, and to that extent plans suffice to be just broad statements. In the interest of compressed time execution, the complete plans may at times not be available right at the start of the mission. These include final targets which can be effectively relayed en-route as long as sufficient details and time is available for the refinement of the initial plan by the combatant. However, eradicating the need for a good plan is wishful thinking if not courting disaster. In order to help combatants compress the planning and re-assessment process, a clear commanders' statement of intention and a comprehensive contingency plan may in fact be essential to ensure clear understanding of commander's intent, common mindset, and unity of efforts.

c. Avoiding Micromanagement

While every single tactical action may be increasingly scrutinized, not every tactical action has strategic ramifications. An approach can be developed to prevent the leadership from spending inordinate amounts of time observing tactical operations. Some recommendations are as follows:

(1) Boundary of Responsibility. While enhanced awareness has brought about the coalescing of the strategic, operational, and tactical domains, due to human limitation in the span of control and the complex nature of warfare, the responsibility boundary of the various levels of war must be recognized and understood. The benefits of collaborative decision making might make it unnecessary to institute rigid

guidelines. However, recognition of the bounds will keep the focus of the commanders at the various levels in check.

(2) Commander's Intent and information flow. The understanding of commander's intent is crucial in the cohesion of forces and unity of efforts. While more detailed planning requirements for the lower echelons can be eliminated by the higher level in view of shared and enhanced situational awareness on the ground, the contingency planning reflective of the commander's intent must be more comprehensive. This will better synchronize the troops' actions with the higher commander, and in return invite less meddling from the top. Essentially, information must not only flow up, in the form of progress update from the lower echelons, but it must also be disseminated downwards, in the form of changes in commander's intent.

(3) Training. Training is essential to attain competency and trust at and among the various levels. Traditionally, training has been focused at the individual and combat entity level to hone individual and combat unit skills. Increasingly, systems level training is more important as NCW is about fighting war at the system level. Familiarity, competency and trust must be established at fighting war at the systems level, so that commanders are less apprehensive and less prone to being control freaks.

E. ORGANIZATIONAL MODEL

1. A Perspective from the A2C2 Program

Circumventing the debate on centralization versus decentralization and networked versus hierarchy, the Adaptive Architecture for Command and Control (A2C2) research program focuses on situational and adaptive organizational modeling. The organizational modeling involves a 3-phase design process (Kleinman et al., 2001). See Figure 2.

The design process is dovetailed by an optimization algorithm involving an array of organizational measures comprising aggregated and dynamic measures, performance measures and measures of congruence. These measures consider variables such as platform processing and travel time, number of co-ordination and information exchange tasks, and performance of organization as related to task processing and decision-maker co-ordination. In addition, a methodology was also incorporated to take account of robustness requirements through a reiterative uncertainty computation .

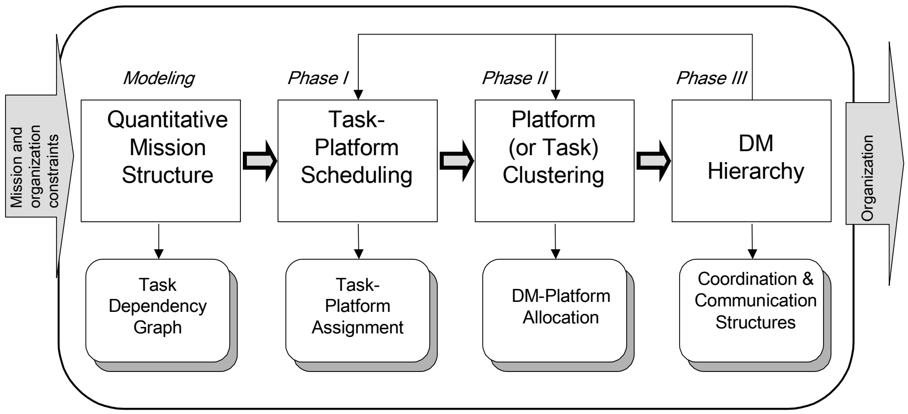

Figure 2. Three Phase Organizational Design Process (From: Kleinman, D.L., Levchuk, G.M., Meirina, C., Pattipati, K.R. 2001. "Design & Analysis of Robust and Adaptive Organization")

The above robust and adaptive organization modeling and design is probably the most comprehensive of its kind to-date. Its practical value is yet to be fully established. Nevertheless, the design could serve as a preliminary guide especially when used together with a thorough analysis of human behavior in organization.

2. A Perspective from Organizational Theory

Based on organizational theory, the objective of strategic organizational design is to obtain total design fit, namely, situational fit, contingency fit, and design parameter fit. Situational fit concerns management style, size, environment, technology and strategy. Contingency fit ensures that contingency relations - if-then statements - have been followed and are compatible with each other. Design parameter fit considers the compatibility of the design recommendations on configuration, formalization, centralization, co-ordination and control, and so on. This approach yields a list of design guidelines and consideration for our C2 organization design. (Burton & Obel, 1995).

F. SUMMARY

Digital networking allows forces to develop speed of command, increase battlespace awareness through the proliferation of COP, and increase combat power. This NCW approach to warfare could draw the C2 organizations towards two opposing directions. On one hand, greater centralization could be a natural consequence, as the fog and friction of war is dramatically reduced, and the compression of time and space bring remote control closer to reality. On the other hand, similar improvement in awareness of ground units permit them to exercise greater initiative to self-synchronize with the higher operational goals with reduced directives. The traditionally hierarchical, service stovepiped, and general conservatism of military organization also imposes impediments to harness the full benefits of a networked environment. A balanced and pragmatic approach must be taken, one that leverages on network technology to achieve greater combat prowess through initiatives, and increased speed of command, while at the same time instituting safeguards to avoid pitfalls such as micromanagement, laissez faire C2 and over-centralization. A flexible and adaptive C2 organization, coupled with a flattened hierarchical structure, remain the best basis for continued experimentation and evolution in our quest for the elusive goal of an optimal C2 organization for a NCW environment.

THIS PAGE INTENTIONALLY LEFT BLANK

IV. C2 PROCESS AND DOCTRINE

A. COMMAND AND CONTROL PROCESS

Command and control serves to provide the decision maker the required information, and facilitate situation assessment, planning and execution. The procedure employed by a commander to effect command and control is termed the Command and Control Process or the C2 Process. In contemporary practice, the C2 process is usually helmed by an operational headquarters (with its decision makers) and often serves a number of functions/roles (Hayes, 2003), namely:

a. Converts policy (guidelines for action) into military directives and ensures that policies are not violated within the theatre.

b. Maintains an assessment of the current military situation

c. Develops strategy and plans

d. Communicates the plans to subordinate commands and ensures co-ordinated actions by those commands

e. Studies beyond the current situation and planning horizon to foresee emerging requirements for the future.

f. Executes strategic operations such as psychological warfare.

g. Provides a variety of expertise services such as technical and administrative.

In serving the above roles/functions in an environment clouded with fog and friction of war, C2 process is inherently designed with due emphasis to ensure accuracy in the passing of command orders, so as to minimize making big mistakes, safeguard against fratricide, as well as achieving optimal cohesion, effectiveness and economies of force. (Alberts et al., 1999).

There are at least three representative models of the C2 process, namely, the Observe-Orient-Decide-Act (OODA) Loop, the Lawson -Moose Cycle and the Headquarters Effectiveness Assessment Tool (HEAT) process. All of these models include semblances of sensing, fusing, understanding, deciding, conveying the decisions, and acting (execution) as part of the C2 cycle.

1. The OODA Loop

Probably the simplest and best known C2 model, the Observe-Orient-Decide-Act or OODA loop is attributed to Col John Boyd, USAF, Retired (Figure 3). This model is derived largely from his experience in tactical warfighting as a fighter pilot in the Korean War, but it serves as a good basic model for the C2 process. Colonel Boyd wrote:

> "The process of observation-orientation-decision-action represents what takes place during the command and control process—which means that the O-O-D-A loop can be thought of as being the C&C [Command & Control] loop … Operating inside [the] adversary's O-O-D-A loop means the same thing as operating inside [the] adversary's C&C loop."

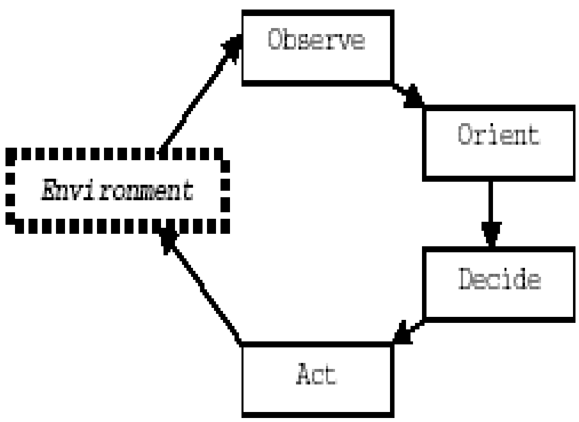

Figure 3. The OODA Loop (From: Kenneth C. Allard. 1990. *Command, Control and the Common Defense* [New Haven, CT: Yale University Press])

Accordingly to Col Boyd, the objective of C2 is to operate within the enemy's OODA/C2 loop by thinking more quickly and coherently. In doing so, one can complicate the enemy's decision cycle, deny him options as it is being developed, thus complicating and eventually leading to the collapse of the opponents C2 cycle, and his defeat. Col Boyd postulated that the C2 cycle is an organic process rather than explicit internal arrangement since much of the loop takes place within the brain of the human.

For that, the model fails to adequately explain all of the command and control activities occurring in the more sophisticate C2 occurring at all levels today.

2. The Lawson-Moose Cycle

The Lawson-Moose cycle is a more detailed C2 model and premised upon the notion that " the purpose of command and control is to either maintain or change the surrounding environment.". (Hughes, 1986).

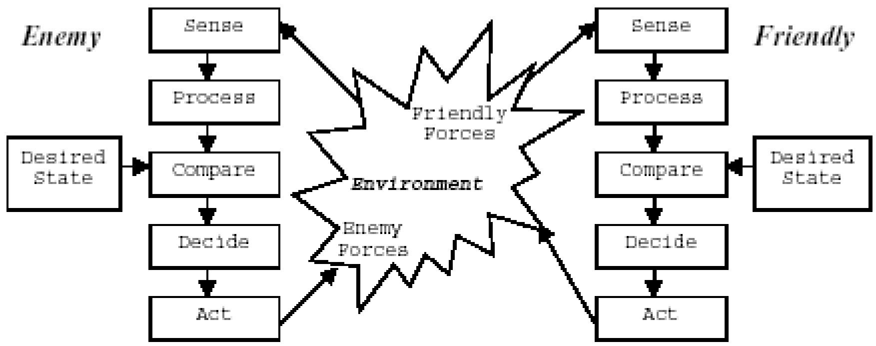

Figure 4. The Lawson-Moose Cycle (From: CAPT Wayne P. Hughes Jr., USN, Retired. 1986. *Fleet Tactics* [Annapolis, MD: Naval Institute Press])

The Lawson-Moose Cycle consists of five-steps, namely, sense, process, compare, decide and act (see Figure 4). Rather then a single 'Observe' block, Lawson expanded it into "sense" and "process" steps. These more discrete steps become useful as the C2 process moves away from something that happens within a single brain, to a more distributed process that encompasses multiple sensors producing data that must be turned into actionable knowledge.

Another feature of the Lawson-Moose cycle is the "desired state" that represents the overall objective of the process and the "compare" step. The "desired state" block can include such items as the commander's intent, essential tasks, the mission statement, or the operations order. The "compare" step (similar to the OODA Loop's "orient" block) examines the current state of the environment against the desired state. This enables the commander to "decide" on the appropriate courses of action that he believes will change the environment to his advantage and amplify the commanders' desire to influence its environment, an element not apparent in the OODA loop.

3. The HEAT Process

Perhaps the most contemporary amongst the C2 models, the Headquarters Effectiveness Assessment Tool (HEAT) process was developed by Dr. Richard E Hayes and others at Defense Systems, Inc., in 1984 (now known as Evidence Based Research Inc.). It consists of monitor, understand, develop alternative actions, predict, decide, and direct steps as depicted in Figure 5.

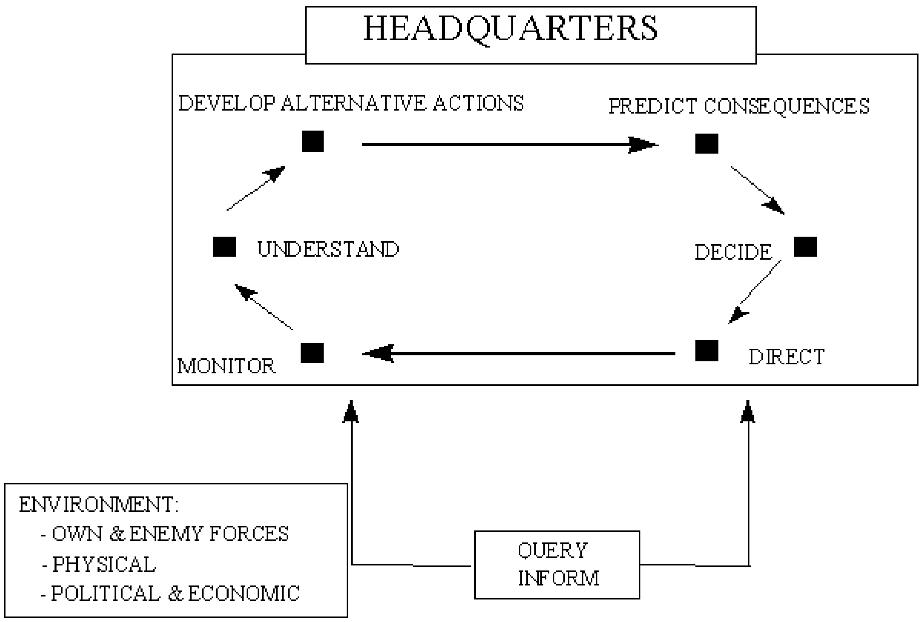

Figure 5. The Headquarters Effectiveness Assessment Tool (HEAT) Process (From: John E. Kirzl. 1999. *Command and Control Evaluation in the Information Age*.)

The C2 Process was viewed as an adaptive control system seeking to attain control over its environment. In order to be effective, this control system must monitor its environment, develop an understanding as to what is happening, develop and assess course of action to control the environment, predict the consequences of selecting a course of action, decide on a course of action, develop a plan, and provide direction to subordinates, and then monitor progress. In a military situation, the environment consists of friendly, enemy and neutral forces (including non-combatants), terrain, and weather, all in the context of the mission to be performed. This process mirrors more closely the institutionalized C2 procedures in today's military organizations, while the earlier models provide a more intuitive and basic framework of the C2 process.

B. THE CURRENT APPROACH

Traditionally, the C2 process has been characterized by an iterative sequential series of steps. These decision or C2 processes exist at various echelons and subordinate loops are embedded accordingly. The speed of the loops is driven by the demand of the highest hierarchy but is in turn constrained by the pace of operations across the entire organization. Typically, the highest operational headquarters will dictate a C2 process through the promulgation of a standardized wartime procedure which will detail the various steps and the timeframe. Such a typical war procedure of the U.S. Army is shown in the figure below.

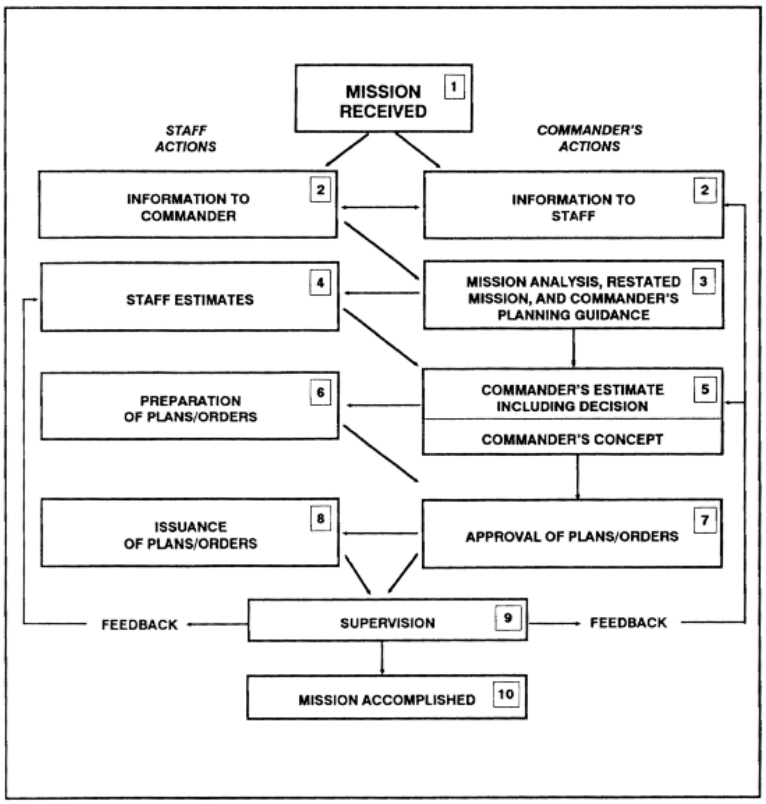

Figure 6. Army's Decision-Making Cycle (From: U.S. Army Filed Manual " The Infantry Battalion". FM7-20)

The current approach to developing a military campaign plan is thus predicated upon a fairly well understood set of relationships among events that take time to unfold. As shown above, the process can be decomposed into a series of steps, each one building on the preceding steps. With each activity executed sequentially, over time, activities at each of the echelons become compartmentalized and highly structured. This process has evolved to the extent that planning and execution could be quite distinct activities, with one level executing the existing plan while another developing the new plan. In addition, this process operates in a cyclical manner. For example, an Air Force can typically operate say about 4 day and 2 night mission windows, depending on the ability to generate combat power. The C2 cycle will then operate within each of these operating windows. In the U.S. Air Force, this cyclic arrangement is further facilitated by means of an Air Tasking Order (ATO) which goes out from a single centralized location to all subordinate units once every 24 hours (or perhaps some shorter period). Each of these ATO takes between 48 and 72 hours to generate, so several are in preparation at the same time.

This current approach to C2 lacks flexibility as each cycle and the associated activities are locked into a fixed timeframe. Each event has to be completed before another event begins. Information that could not meet the earlier cycle will fall into the next C2 cycle. This omits the importance of time sensitive information, synergy and integration of the various activities and events. Combat power and sometimes critical opportunities may be lost as a result. The highly structured procedure and process provide a systematic approach to an otherwise complex task by breaking down the task to more manageable building blocks.

C. THE EVOLUTION OF C2 PROCESS

The emergence of NCW is revolutionizing the C2 process. First, it compresses the execution of the C2 process in the time domain. Second, it is merging the current discrete and largely separate planning and execution processes. Third, it is harnessing greater flexibility through self-synchronization.

1. Time Compression

This is the most direct and apparent impact of information technology. The communication intermediaries of couriers and runners had given way to a seamless global communications grid with increasingly larger bandwidth. The speed of communication is no longer hampered by the physical limitations of the couriers and runners to traverse geographical distance, but rather facilitated by digital communications technology that could go round the earth many times within the wink of an eye. This has dramatically compressed the C2 cycle. The entire C2 cycle is more responsive to the environment due to the shorter decision loop. As a result, combat effectiveness is gained as the lapse between desired effects and execution is reduced, minimizing the loss in combat power /effects.

The time compression of the C2 cycle of both opposing forces also means that the pace of warfare is intensified. Warfare is happening as fast as the information flows. This could mean greater and overwhelming workload in processing the information, especially without effective information management tools.

2. Collaborative Planning and Execution

The three primary C2 functions of Decision-making, Battlespace Visualization and Management can be depicted as a set of spheres (See Fig. 7). Monitoring and understandings of the situation are located in the Battlespace Visualization sphere, alternative courses of action, predictions, decisions, and plan development are parts of the Decision Making sphere, and direct, disseminate and execute are in the Battle Management sphere, with information providing a linking mechanism between the spheres.

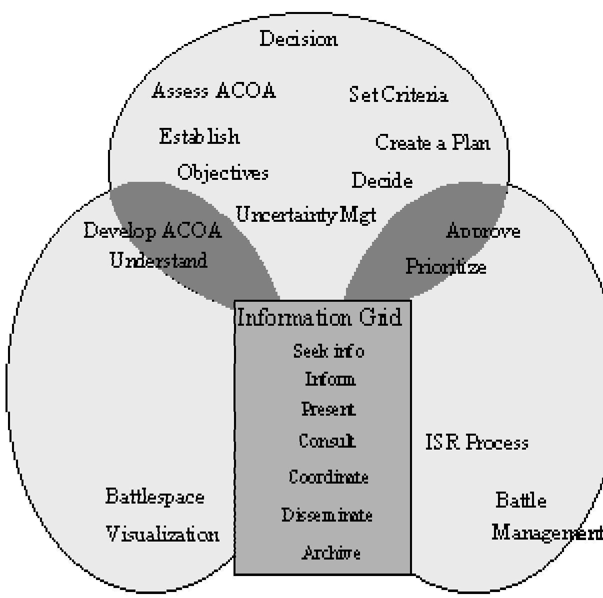

Figure 7. C2 Functional Spheres (From: John E. Kirzl. 1999. "Command and Control Evaluation in the Information Age".)

Dr. Hayes suggested that as the information and networking grids mature, information will become ubiquitously available to all levels simultaneously. (Kirlz, 1999). This will result in the three functional spheres coming closer together, creating interesting conjunctions and intersections (See Fig 8).

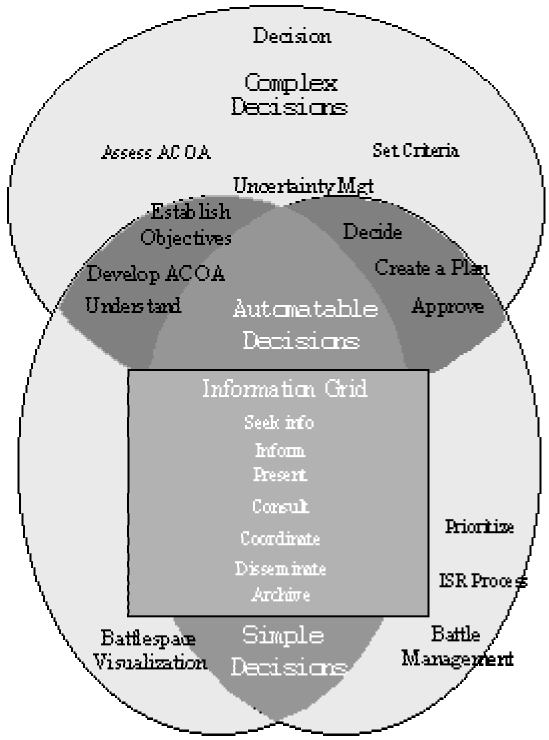

Figure 8. C2 Functional spheres linked by Information (From: John E. Kirzl. 1999. "Command and Control Evaluation in the Information Age".)

As a result of the mutual awareness between Battle Visualization (planning) and Battle Management (execution) domains, both activities no longer need to be conducted discretely and separately. Instantaneous feedback is possible as planners can 'watch' the effects of their plans and immediately reflect the new battlespace situation in their planning. The activities no longer need to be segregated due to the arduousness and sophistication in gathering the information and understanding the situation. The potential benefit is the greater synergy of efforts from planning to execution, and greater responsiveness of the plans to the actual situation on the ground. A benefit of the merging planning and execution process is the reach back capability. Aided by the communications technology, targeting information no longer needs to be available to the combatant at the point of initiating the mission, but rather provided at a later time when plans catch up with the execution cycle or when more updated information is available. This further compresses the C2 cycle and makes the plans even more responsive to actual ground situation.

3. Harnessing Greater Flexibility

Given the common battlespace awareness across the three domains, decisions in an network centric environment can be generated in different domains depending upon the nature of the decision. Complex decisions, requiring complicated and thorough analyses of courses of action and available options, continue to be parts of the Decision Making sphere. Contingent, or simple, decisions, which are those requiring only that the commander (staff) understand that the situation matches a planned contingency, occur at the intersection of the Battlespace Visualization and Battle Management spheres. The reduction of uncertainty resulting from the vast improvements in information availability will allow many previously complex and/or contingent decisions to be automatable decisions (e.g., target/weapon pairing). They occur at the intersection of the three spheres and are characterized as rapid, pre-planned, and requiring no human intervention. This allows the operational headquarters to focus on higher level decisions, and provides the freedom of the lower echelons to act with the improved situational picture. This expedites the C2 process by reducing the planning requirements at the higher echelons while enhancing the execution by having the decision done at the level where it can be done most efficiently.

NCW provides new opportunities to improve the highly structured and institutionalized C2 processes that we are accustomed to. These opportunities come about as communications speed has increased manifolds, and networking has enabled common awareness and more knowledgeable combatants along the C2 chain. These opportunities are manifested in the time –compressed C2 cycle, collaborative planning and execution, enhanced flexibility and self-synchronization attributes in operations. The C2 process must be revamped to exploit these opportunities. Several things ought to be done:

a. Reassessment of the timeframe of previous events/activities.

b. Identification of the 'automatable' decisions, new framework of tactical and operational decisions, as well as new planning requirements at headquarters.

c. Planning and treating C2 more of a continuum inextricably linked with execution, rather than a start-and-stop activity of a fixed period.

D. C2 DOCTRINE

With new ways of operation, changes would certainly be required in the operational doctrines. There are several levels of doctrine, the highest level and the most enduring of which are the principles of war. In the U.S. doctrine (US JCS, 1991), the principles of war comprises Mass, Objective, Offensive, Security, Economy of force, Maneuver, Unity of Command, Surprise and Simplicity. While these principles remain largely relevant, new interpretations are necessary where the essence of NCW brings about new meaning to the status quo.

Lavee en Masse has provided the ultimate answer to the principle of Mass since the Napoleonic era. However, in NCW, it is no longer sufficient to interpret Mass as singularly predicated on human soldiers/weapons. In platform-centric attrition-based warfare, fire power is effected through the massing of forces. In network centric effect-based warfare, such is not necessary, though important. The geographical gap can be bridged by moving information to allow dispersed forces to deliver devastating and massive effects on a common location, and target. In fact, in NCW, the massing of effects results in a smaller footprint of the operations, as it may not require the massing of forces physically, or at least not to the same extent. This not only increases survivability of the forces, but also imbues greater flexibility in the conduct of the operation.

"Unity of Command is to ensure unity of effort under one responsible commander for every objective.". (U.S. JSC, 1995). Unity of effort remains the ultimate objective to achieve synergy of efforts. However, increasingly, the existence of unity of command in an increasingly well-informed network and dynamic situation, may not be the imperative. Nevertheless, a laissez faire scenario of autonomous ground forces self-synchronizing towards the command objective may remain a distant dream.

Security will remain increasingly sophisticated and susceptible to attacks on the networking grids. Unlike previously when most information was compiled at the higher headquarters and compartmentalized at the lower echelons, the knowledgeable combatant of NCW requires that information also be sent to the ground forces. The security of the networking grid and its freedom of use will increasingly be the backbone and enabler of NCW, and hence subject to more sophisticated attacks and counter-counter operations.

Simplicity is critical in ensuring complete understanding and ease of execution, especially in the midst of the fog and friction of war. With the vision of NCW clearing the fog and friction of war at least to a certain extent, increasingly more complicated operations may be possible, if information dominance is achieved. Spurred by the general public's over–expectation of military capability and the humanistic concerns fed by the media, combat forces will have to contend with the adverse effects of the media by painstakingly showing that only appropriate force are used and collateral damages minimized.

At the lower levels of operational doctrine, more extensive changes would be expected. However, this doctrine will be premised on the new concept of operations in the new information paradigms, many of which are still in development. Such doctrine will have to be continually evolved through operational and experimental exercises, as well as actual operational experiences.

E. SUMMARY

In military operations, the C2 process is a critical part in the waging of campaigns and fighting of battles. The emergence of NCW is deemed to revolutionize this otherwise extensively institutionalized and well-oiled process. The highly structured process needs to incorporate the new opportunities arisen from NCW, such as a compressed C2 cycle, collaborative planning and execution, and greater flexibility through reach back and self-synchronization capabilities. The mindset of a cyclical and mutually exclusive process must be replaced by one of a continuous and overlapping continuum of planning and execution. The exploitation of these new opportunities will harness increased yields in combat power.

Changes in ways of conducting operations will inevitably induces changes to the operational doctrines. At the highest level of operational doctrine, the principles of war remain largely unchanged though new interpretation might have to be incorporated to reflect the new paradigms of NCW. At the lower levels of operational doctrine, changes will take place more extensively and evolve with the development of new NCW concepts of operations.

THIS PAGE INTENTIONALLY LEFT BLANK

V. C2 INFOSTRUCTURE AND SYSTEMS

A. PURPOSE

The C2 Infostructure and systems are the vital backbone and enabler of Network Centric Warfare. The C2 infostructure essentially refers to the information infrastructure comprising an integrated network of communications and computational links that provide the seamless connectivities among all its subscribers. The C2 systems here refer to the applications, information management tools or computer subsystems that often ride on the infostructure to provide the information exchange and decision support functionalities used to facilitate the command and control process.

The C2 Infostructure and systems serve many purposes:

a. Information Dissemination. First and foremost, it facilitates communications. Traditionally, C2 nodes pass information, including orders and instructions, through voice and fax. These are usually subject to human errors (e.g., hearing the wrong message) and limitations such as, requiring the immediate attention of the receiving party, and suitable for short and simple information/instructions. For faxing, there can be substantial time lapse in transmitting the document depending on the length of the document. Increasingly, modern digital communications are employed for messaging, document and picture transfers, and in many cases, they replace the need for faxing and voice communications.

b. Information Management. With the deluge of information, the potential for information overload is real. As a value-added service, it is important for C2 systems to ensure that what is provided or received is actually information and not noise. Moreover, information should be organized according to their relevance to facilitate ease of retrieval.

c. Knowledge and Decision Support. With the increasing pace of C2, the blazing speed of modern communications, and the expanding span of control, information needs to be quickly assimilated as knowledge to decide and respond to the situation. At the same time, more decisions need to be made and quicker responses are demanded. Knowledge and Decision support need to be automated to at least ease the workload for the processing of the more mundane, and simple information collation and decision-making. This will prevent decision-makers from being overwhelmed by the sheer volume of the information and tasks.

d. Automating Process. Ideally, the processes should be built into the systems so that the processes can take place most efficiently without the manual and unwarranted interruption of the human operator. This will reduce the learning process and workload in using the systems.

B. INFOSTRUCTURE

In essence, the NCW approach is about the moving of the right information very quickly, at the right time, and to the right place (assuming that information is correct and person has the knowledge to make the right decision). This information can be categorized into the following:

a. Battle Information. This encompasses all operational data and information regarding the conduct of the battle from mission schedules, ammunition availability, manpower status, to orders and battle plans.

b. Tactical Coordination and Control. This entails all forms of realtime co-ordination and control communications between combat entities on combat operations. This usually comprises complementary voice and messaging utilities, at least until voice communications becomes totally obsolete.

c. Situational Awareness. In an NCW environment, situational awareness is facilitated by the dissemination of COPs. Battle knowledge is derived from this situational picture coupled with the battle information to provide commanders the premise for decision making.

d. Targeting/Engagement Information. Engagement quality information requirements are realtime targeting data to facilitate threat assessment, closure prediction, and distributed weapon-target assignment. This information, derived from multiple sensors or a single most reliable source in the proximity of the target, usually consists of accurate position/velocity and friend-and-foe identification. Such information enables precise engagement of adversary forces across the depth and breadth of battlespace with not only the line-of-sight weapons in the threats' immediate vicinity but also a wide spectrum of beyond line of sight weapons in the area of operations.

Based on the information requirements, the future framework of the infostructure can be constructed in four grids according to the information categories. By and large, the categories will also streamline the link requirements based on the quality of service, particularly the link latency, data rate, error tolerance, and delivery confidence. These four grids[1] are:

1. Information Grid

The information grid is an information highway, primarily among the command and control nodes. It serves the infrastructure to "receive, process, transport, store, protect and even value-add on information" among all its subscribers. Voice, data, and video can be transmitted, usually via broadcast mode in the majority of cases. It is a repository of all battle information such as orders, plans, and mission schedules. The grid provides access to a large volume of information with delay tolerance in the order of seconds/minutes.

2. Tactical Control Grid

The tactical control grid serves as a communication platform to provide realtime coordination and control among its tactical users and C2 centers. The information relayed can be voice, data, video transmitted via point-to-point or direct broadcast. As the information relayed on this grid is highly perishable and time sensitive, it has low tolerance for transmission delays, usually in the order of sub-seconds.

3. SA (or Situational Awareness) Grid

The SA grid serves as the data pipe for sensor information and provides the users with situational awareness across the battlespace. This grid links all sensors in a battlespace and fuses the sensor data (primarily track information) to provide a more accurate and comprehensive battlespace picture. These sensors may comprise air-, sea-, ground-, space-, and cyberspace-based sensors. They may be dedicated sensors, sensors

[1] In much of the NCW literature (Alberts et al., 1999; Cebrowski, 1998), only three grids were suggested, namely information, sensor and targeting. I have included a tactical control grid which I perceive to be an important category that ought not to be subsumed into the information grid – the realtime requirement sets it apart from the majority of the information requirement. It must be noted, nevertheless, that the categorization is arbitrary and intends to provide a comprehensive conceptual framework. It is hence subjected to optimization during technical implementation, provided that the essence and utilization of the various grids and pertaining requirements are not compromised).

based on weapons platforms, sensors employed by individual soldiers, or embedded logistics sensors. Platform commanders are thus no longer limited to only the sensor data provided by their platform sensors, but have direct access to a common and comprehensive situational picture.

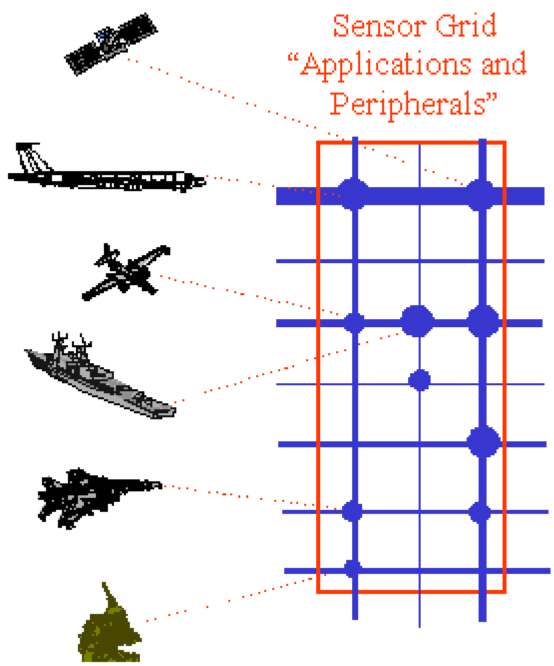

Figure 9. The Situational Awareness (or Sensor) Grid. (From: Stein, Fred P. 2003. "Observations on the Emergence of Network Centric Warfare". Evidence Based Research Inc. <http://www.dodccrp.org/steinncw.htm/>> [29 Oct 2003])

Sensors and the SA grid can be both persistent and transient. In other words, they can both be dynamically assigned to support different mission requirements thus allowing optimal use of resources. The acceptable delay tolerance defers according to the battle arena. For situational awareness regarding the land troop or surface ship, typically delay tolerance in order of minutes or seconds is not a problem. However, in air battle, the sensor data must be highly accurate and the delay tolerance should be below sub-second.

4. Targeting/Engagement Grid

The targeting/engagement grid allows subscriber access to any weapon systems in the battlespace. It links all weapon systems via the network and entails high-end network performance in terms of high data rate and very low latency information transport capabilities to achieve cooperative sensing and engagement of high speed targets. Sensor data may also be included, and usually when used for the purpose of targeting or engagement, the data must be very accurate to provide the required engagement precision. For this reason, sensors are often integrated at the plot level. As with the SA grid, the targeting/engagement grid may be persistent or transient in nature, activated on a demand basis. Due to the low latency tolerance, the grid is however limited in its spatial distribution, and is usually for weapons/sensors within the immediate locality of the target.

C. C2 SYSTEMS

At the heart of command and control is a full spectrum of information management tools or command and control systems, that facilitate and aid decision-making, disseminate orders and plans, control and execute missions, and monitor and supervise activities. Typically, the command and control systems will contain elements of Headquarters Battle Management Information Systems which provide commanders the 'global' battle information needs, Campaign/Mission Planning tools, Orders Dissemination and Mission Monitoring System, In-flight Command and Control systems for realtime tactical control, and etc. By virtue of the hierarchical organization, these systems used to be stove-piped along the functional divides. Hence, the first generation command and control systems in the modern computer age were generally functionally oriented based on structured design technique (Fassbender & Stein, 2004). The proliferation of wireless communication systems using different protocols, the difficulty for coalition forces to communicate over such systems, and the difficulty of coordinating both police and fire activities on Sep 11 are examples of the present state of stovepipe systems, both military and civilian (Logan, Aug 2003). The realization of the synergy of information and the needs for integrated information tools at the various combat levels drove subsequent development towards the lateral integration of the stove-piped systems. This led to a "matrixed" systems development approach with stove-piped systems continuing to serve functional needs and new operational systems being customized to the needs at the lateral levels. This matrix construct resulted in highly complex and unwieldy integration of multiple systems which become too expensive to develop, modify and maintain. Today, the network and internet protocol usher in a new network - based design orientation that eases the implementation of the command and control systems. In addition, new facilities and tools are being introduced into the command and control arena, from basic e-mailing and collaborative systems to increasingly sophisticated decision support modules.

D. AN HETEROGENOUS ARCHITECTURAL FRAMEWORK

In an ever-changing and dynamic environment where we have little a priori knowledge of the foreseeable future and conflict, it has become important to establish a set of rules, guidance, and principles to align the development of future C2 systems in order to ensure mission-effective and expense efficient end-products. Such an architectural framework, known as "The Advanced Technology Architecture for Information Superiority (ATAIS)" was conceived by the Defense Advanced Research Projects Agency (DARPA), U.S. DoD. While ATAIS is not yet a complete architecture with a complete set of specifications, it provides a strategy and overarching considerations for building future C2 infostructure and information systems.

The ATAIS is driven by two sets of important overarching requirements, namely, operational and technical (Hayes-Roth 2003). The driving operational requirements entail:

a. Dynamic creation and employment of an information infrastructure suitable to support distributed cross-functional organizational elements for mission or task duration,

b. Direct access to mission or task-related information independent of the user's location, information source, and command structure,

c. Continuous, consistent battlespace awareness, including execution monitoring and information collection management,

d. Significant increases in speed of command, including predictive planning and reasoning with unstructured information,

e. Self-synchronization of dispersed, disparately equipped, multilingual force elements based upon widespread understanding of the Commander's Intent,

f. Rapid target recognition and attack, including dynamic sensor-weapon and weapon-target pairing,

g. Maintenance of Information Superiority through offensive and defensive Information Operations.

The driving technical requirements specify the following considerations:

a. Interoperability – the architecture must facilitate the interoperation between constituent systems, including those created in the future as well as those already deployed by the US and potential coalition partners.

b. Composability – the architecture must facilitate the rapid creation of new applications and new processes in response to new missions and threats by allowing users to quickly compose off-the-shelf components in new ways, and easily modify and reconfigure systems and applications to meet changing missions and threats.

c. Functional Integration – the architecture must support the integration of a large number of applications based on a common business process, achieving complete coverage of the process while minimizing duplicated effort and resources.

d. Achievement of Global System Performance Characteristics – the architecture must facilitate the achievement of important global system performance characteristics including security, mobility, distributability, flexibility and adaptability, automation, robustness, reliability, scalability, and responsiveness. Each of these characteristics should be attainable to the degree required to satisfy mission needs and achieve the commander's intent. Tradeoffs between global performance characteristics should be dynamically adjustable by the warfighters for a broad range of situations.

The structure of ATAIS is depicted in Figure 10 below. It comprises three basic architectures: The *Operational Architecture* which represents the tasks and activities, operational elements, and information flows required to accomplish or support a military operation; the *Technical Architecture* which gives the minimal set of rules governing the arrangement, interaction, and interdependence of system elements to ensure that a conformant system satisfies its requirements; and the *System Architecture* which associates physical resources and their performance attributes to the operational architecture and its requirements per standards defined in the technical architecture. The hierarchy of Domain-Specific Software Architectures (DSSA) is the building block for the complete architecture.

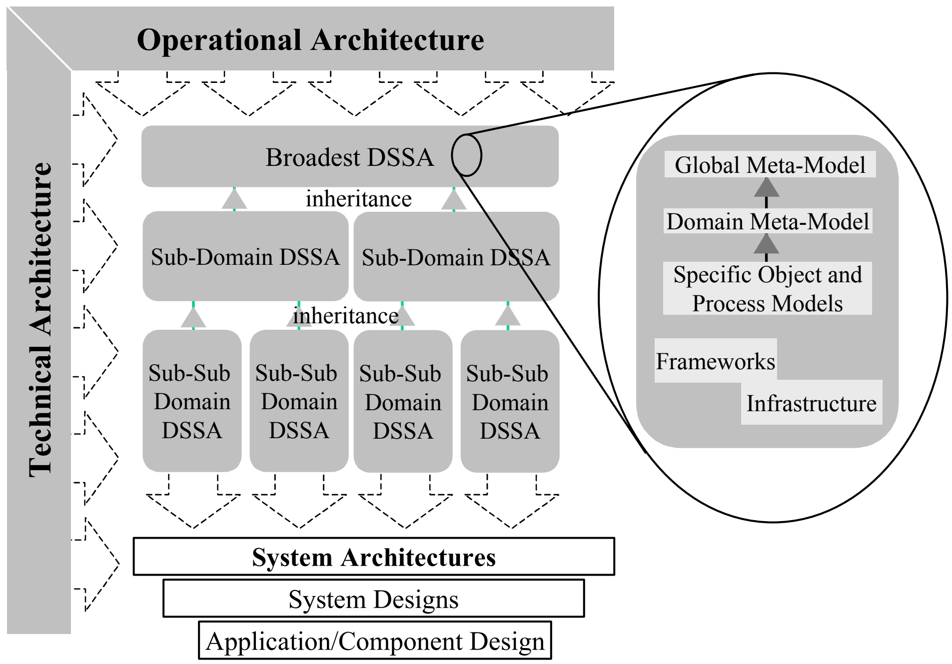

Figure 10. ATAIS Structure (From: Hayes-Roth Frederick. Sep. 2003. "Architecture, Interoperability, and Information Superiority").

1. Operational Architecture

The operational architecture essentially outlines the business process models of the organization. It is critical to build-in the business processes so that the systems can follow the business rules without intervention from the human operator. This is unlike traditional C2 information systems that just automate a small piece of the entire task, instead of facilitating the entire process. The operational architecture also takes cognizance of the close-loop decision and execution cycle, the increasing reconfigurability and flexibility in team composition, and the fractal nature of control in the organization.

2. Technical Architecture

The technical architecture propounds five guiding principles that minimally constrain system design. These are :

a. **Achieve semantic interoperability using a Common Meta-Model.** A common meta-model approach is the most promising way to achieve inter-operability to large scale architecture-based development within a heterogeneous organization. The semantics of an object comprises its states, the rules governing its behavior, and the meaning of its interfaces and capabilities. Thus semantically interoperable systems share common meaning and reduce the effort needed to develop interoperable systems. In comparison, interoperability design based on syntax compatibility exchanges data using agreed upon data formats and structures requires more substantial integration effort.

b. **Support multiple levels of interoperability.** Having multiple levels of interoperability represents a practical solution to large organization whereby it is impractical to develop a comprehensive global object model shared throughout the organization. The levels of interoperability – from systems that use a common database, to loosely interoperable message-based systems, to tightly integrated applications can be implemented using the same technical component frameworks. The level of specificity of their shared object model will determine the degree of interoperability between two systems.

c. **Achieve composability by embracing Component Technology.** In order to achieve rapid application development, increase software reuse and allow less skilled operators and technicians to create applications, component technology ought to be embraced. Microsoft's COM/DCOM/.NET, Sun's Java Beans, the OMG's CORBA, and the web services of OASIS/W3C are examples of technologies that support application composability. The development trend in this arena has been the standardization of component technologies and an understanding of proper development practices that facilitate reuse and interoperability.

d. **Thoroughly Exploit Commercial Technology.** The breathtaking pace of technological innovation in the commercial marketplace has created enormous opportunity to harness more cost-effective commercial solutions to achieve information superiority. However, the same technology is also available to our adversaries. Thus, we must continue to keep up with these commercial technologies and make best use of them, while at the same time focusing R&D resources on areas not addressed by the commercial market to deliver the silver bullets. In order to keep up with the pace of technology revolution in the commercial world, dramatic improvement must take place in the way military acquisition and project management are being done. Most important of all, there must be a paradigm shift in the timeframe of such processes. Otherwise, the time when we ushered in a new system might just be the time it becomes obsolete in the commercial world.

e. **Embrace Heterogeneity while Promoting Standards.** To build advanced applications, system implementers must be able to choose from the best available solutions. On this premise, a heterogeneous approach must be taken to implement IT systems. On the other hand, the use of well-defined interfaces and adoption of open standards are also crucial for achieving interoperability and composability. Thus, the military should stay open to the competing technologies, specifications, and standards while promoting standardization when the technology reaches maturity.

The Boeing Company, similarly, outlined a technical architectural framework that they called Strategic Architecture Reference Model (SARM) to facilitate Network Centric Operations. It is worthy to note that while Boeing premised their technical approach upon standards, particularly Internet Protocol, the U.S. DoD advocated an heterogeneous approach. The U.S. DoD advocated consolidating established standards through an evolutionary and market survivability concept instead of putting the bet essentially on just one horse. The Boeing approach, on the other hand, adhered to a common interface and functionally and common ontology. It is a more simplistic model and may be suitable for smaller Armed Forces. The caveat is that the approach locked itself onto a particular technology. It has to hence continually be alert and agile to technological changes.

E. OPERATIONALIZATION

In ushering in new systems and operationalizing the systems' capabilities, there are a number of pitfalls or myths that organizations must try to avoid.

a. <u>The Myth of "Shorter Learning Curve".</u> This is only a half truth, at best. It may be true that with computer literary continuing to rise, and commonly established human-machine interface norms becoming more intuitive, the learning curve for the 'keyboard activities' and navigational functionalities of application programs is shortened. However, this simplistic observation runs the risk of rendering the significance of the automated backend work processes into oblivion. The emphasis of training should shift from the ‘keyboard’ activities to the mechanism and workflow of the processes. Organizations that trivialize training as a result of the advent of ‘smarter’ systems must bear the risk of being eventually driven by the process and not being able to take charge of it in the long run.

b. New Tools require New Rules. A primary finding from "Bridge to Global ’99" was that the proliferation of new information systems and tools requires a brand new set of rules, protocols, and guidelines-for-use to help teams understand when and how best to use them (Kemple, 1999). Given our traditional use of audio communications as a primary means of coordination, the developed protocols and methods may no longer be the best fit for the new, network-based collaborative tools. We need to better harness the benefits of these new systems and minimize their ills. Thus, it would be useful to evolve new usage guidelines for email, chat, videoconferencing, shared graphics spaces (i.e. whiteboards and common map displays) and other network communication tools aimed at harnessing the optimal benefits of these new tools The guidelines should aim to shorten the learning time for new tools, without stifling any creative usage of the tools for operational gains.

c. The misperception of information. As a result of greater information flow and continuous update, there is a perception that every combatant will have access to all possible information, and will therefore be constantly "situationally aware." (Kemple, 1999). This misperception can be hazardous, For instance, it could lead to false expectation, resulting from belief that others know things that they do not. It could also result in unproductive information dissemination caused by individuals pushing unintelligible data to others assuming that by doing so, the responsibility of informing others was fulfilled. Information assimilation is not just a simple process associated with the ‘cc’ function in e-mailing, but is an involved process of information filtering, fusion, storage and retrieval.

F. SUMMARY

The Command and Control infostructure and systems suite is a critical enabler for Network Centric Warfare. A cogent and visionary architectural framework must be in place to guide the development of the command and control systems to be mission effective and effort efficient. In ushering in the new systems, we may need new ways of operating and should take cognizance of some of the lessons learned in our preliminary experiences with these new systems.

VI. THE ROADMAP TO NCW

A. KEY SUCCESS FACTORS

To make Network Centric Warfare a reality, a number of conditions or key success factors must exist in the organization. These include aligning the organization's commitment, resources and efforts, fostering a learning and innovative culture, constructing a seamless, robust and secured infostructure, and establishing measurement of effectiveness or performance of NCW.

1. Organizational Alignment

Like any change management, and more so for one which is so complex and laden with so many uncertainties, organization alignment is critically important in moving the organization to its desired state. First and foremost, there must be an alignment of attitudes. The commitment of the leadership and the buying-in of commanders and all the men and women across the entire hierarchy is the bedrock for a successful transition. Not only should this commitment be articulated, but it must be institutionalized because the transformation from platform-centric to network-centric warfare is a long haul, it is a journey meant for the marathoner, not the sprinter. Second, there must be an alignment of the resources and efforts. Archetypes of such alignment are investment strategy, research program, long term capabilities plan, and all the related processes. Without optimizing resources and efforts, wastages and confusion may result in a loss of focus, leading to a failure not of the vision, but the implementation.

2. A Learning and Innovative Culture

The only constant in a dynamic and rapidly changing world is change itself. The end-state of NCW remains visionary, and many researchers admit that we may only be at the beginning of a revolution. Fostering a learning and innovative climate is thus essential in capturing creative new ways of meeting our mission objectives. Old mind sets and operating models must be discarded and replaced by the new realities of NCW. The pillars of a learning organization outlined in Peter Senge's Fifth Discipline (Senge, 1990), namely, system thinking, personal mastery, mental models, building shared visions, and team learning must be cultivated to continually expand an organization's (and all its individuals') capacity to learn, nurture collective aspiration, and create results truly desired. Our success in NCW transformation will not only depend on technology advancement, but in fact, more importantly on our ability to conceive, experiment with, and implement new network-centric ways of doing business that leverage the power of Information Age concepts and technologies, and transform them into new capabilities that NCW promises.

3. Entry Fee

Infostructure is the entry fee to NCW. An infostructure that is secure, robustly networked, seamless, and coherent will enable NCW, facilitating network-centric learning and operations. Without a seamless, robust and secured infostructure, network centric operations cannot take place optimally, and in fact, the network susceptibility and vulnerability may compromise our mission more than value-adding. The upfront investment in extensive and robust networking is thus inevitable and critical. An infostructure architecture framework and implementation strategy must be established upfront in order to maximize standardization and reusability of components, and determine the most cost–effective solution. In exercising financial prudence, it is important not to be 'penny wise and pound foolish'. Systems requirements or 'quality attributes' must not be compromised in preference to meeting functional requirements. In order to harness innovation and rapidly advancing technology in the commercial sectors, open standards and off-the-shelf technology should be adopted as far as possible, but without compromising important systems level requirements.

4. Co-evolutionary Development

The delivery of NCW capabilities does not rest singularly on technology. It would be far too simplistic to consider that everything is driven by a single factor, from which everything else evolves. The mutual influence and sophisticated interactions between the many factors mean that holding a single factor constant, and fine-tuning the other factors around it may be counter-productive. Development of NCW must be considered holistically as a co-evolution of technology (Material), organization, and process (Doctrine, and also Tactics, Techniques, and Procedures) (Cebrowski, 1999) in order to achieve dramatic improvement in our warfighting effectiveness. This is what transpired as the disruptive innovations of *Blitzkrieg* and Carrier Aviation matured from concept to reality.

5. Measures of Effectiveness/Performance (MoE/MoP)

There is a saying that goes 'Performance that cannot be measured, will not be achieved'. In today's corporate culture, where the management objectives are specified in numbers, whatever cannot be specified will fall outside the realm of top priorities and many a times reduced to rhetoric. Only when the attributes of performance and effectiveness can be measured, will organizations be able to track progress, amass organizational resources more optimally, and instill organizational discipline to stay the course for the long haul. However, the search for the holy grail of overall C2 MoE/MoP has been elusive.

6. Incremental and Evolutionary Approaches

The road towards NCW is a journey, it is for the long haul. We cannot specify the end-state in any greater detail than what we know of the technology and the environment today, so we need an evolutionary approach to sharpen our vision as the environment changes and our concept crystallizes. It would be impractical to wait till only end of the journey to see the product. We must take a progressive approach to put up landmarks along our journey to act as lighthouses to steer our direction. We need to provide the incremental successes to invigorate the organization to continue its NCW pursuit.

B. THE ROADMAP

In implementing the first Revolutionary in Military Affairs (RMA) in the 21st century, we need to devise a roadmap. It will serve to identify the landmarks along the journey and a compass to continually prevent us from going astray. The following suggested steps for NCW roadmap are consolidated from the many literatures on NCW.

1. Understanding and Appreciating NCW

The most fundamental step towards implementing NCW organization–wide is to foster an organization-wide understanding and appreciation of the basic tenets of NCW, its basic concepts and expected benefits. The primary objective is to achieve corporate buy-in to the vision of NCW. Rather than forcing people to adopt a new concept, it would be more fruitful to get the basic ideas of NCW across to the people, and hopefully, they would embrace the concept. Even if it does not achieve total buy-in of the masses, the process would eradicate some impediments and encourage desirable emergent behaviors along the way. Moreover, only with more people who understand and appreciate NCW, could more thoughtful discussion be generated about the subject. Given human nature and the sheer size and diversity of a military organization, it is inevitable that different enclaves may have different interpretation of the basic NCW ideas. An healthy competition of the different schools of ideas should in fact be encouraged so that better and more innovative ways of employing NCW can emerge consequently. The publication of Network Centric Warfare: Developing and Leveraging Information Superiority by U.S. DoD CCRP (C4ISR Cooperative Research Program) is a step in this direction. The concluding paragraph of its Introduction reads (Alberts et al., 1999): "Since successful adoption of NCW required a cultural change, it cannot be achieved without widespread discussion, debate, experimentation, and ultimately broad acceptance. If this book stimulates and contributes to this process, it will have achieved its intended effect."

2. Establishing the Infostructure

Networking the organization must be one of the first steps to kick-start the NCW efforts. An adequate infostructure, with a critical mass of connectivity and interoperability, is necessary to both support and promote information sharing and collaboration, and to enable new approaches to command and control. Connectivity is important. According to Metcalfe's law, the potential value of a network is a function of the square of the number of nodes that are connected by the network. However, its importance cannot be over-emphasized. More connectivity may be a cost liability and maintenance nightmare if it is not targeted at where it delivers the combat prowess. Rather, 'quality' attributes - as opposed to functional - of the infostructure, for example, performance (real-timeliness), robustness and security are also critical. A network that has poor security attributes would render the forces susceptible to information attacks or exploitation. Poor reliability would frustrate the operators, and instead of encouraging network centric operations, it would in fact achieve the exact opposite.

The development of the network should not be left to a state of lassie faire. It must be governed by a good implementation strategy to meet the demands and best deliver the benefits. The basic network grids are outlined in Chapter V. Systems level optimization and standardization must prevail in order to maximize inter-operability, and inter-operability considerations must have a strategic focus and not be sacrificed for near-time considerations.

3. Organizational Blueprint and Architectural Framework

Establishing an organization's architectural framework or blueprint for NCW is an essential next step towards NCW. The value of an architectural framework is that it provides a holistic methodology and the mechanisms to facilitate efficient and effective co-ordination processes, information flows, systems, and investments within the organization, thus helping to optimally align the organization's resources to focus on the achievement of NCW benefits. The common framework for planning, defining, and integrating will serve as repository of information and tools for organizational wide implementation. It will promote inter-operability standards and resource sharing, minimize data collection burden, and focus creativity and innovation. It is more than just a vision statement. With reference to Architectural Standards (Percivall, 2002), an architectural framework that meets all the standards is a comprehensive working model that details the responsible organization, scope, processes, and standards. There are a number of methodologies for creating an architectural framework. Probably the most renowned is the Zachman framework which provides a common context for understanding a complex structure. The CIO Council employed an expanded version of the National Institute of Standards and Technology (NIST) model in developing the Federal Enterprise Architecture. The five-layered model (as shown in Fig 11) allows for organizing, planning, and building an integrated set of information and information technology architectures.

There are a number of approaches in developing the Architecture Framework. Three of these approaches are outlined below (CIO Council, 1999) :

a. **Conventional Approach** – A most comprehensive and holistic approach. For complex organization or target architecture, this approach may result in "paralysis by analysis", and would require a substantial initial investment in time and dollars upfront before any results could be visible.

b. **Segment Approach** – An evolutionary approach that promotes the incremental development of architecture segments within a structured organizational architecture framework. This approach focuses on the major value chain that cuts across functional areas of the organization. Contrary to stove-piped structure which focuses on development areas, the segment approach integrates laterally across the organization to deliver the desired organizational output.

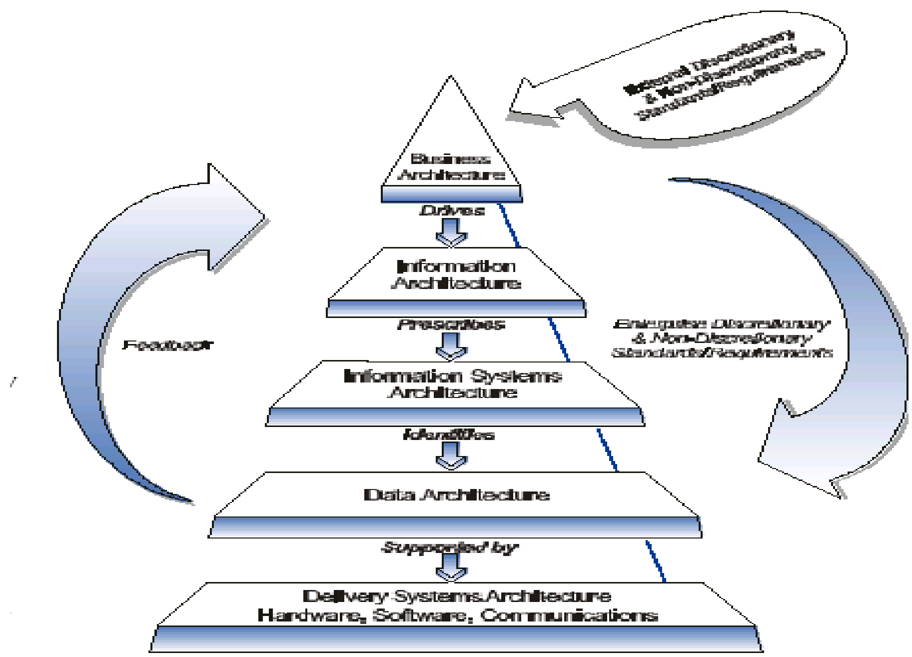

Figure 11. NIST Enterprise Architecture Model (From: CIO Council. 1999. *Federal Enterprise Architecture Framework.*)

c. **Status Quo Approach** – This is a business-as-usual approach. It provides an architecture framework for current process, without the drive to achieve increased optimization process and has no focus due to lack of vision of a desired state.

The choice of the approach is critical to the success of developing an effective architectural framework for the organization. Given the complexity of military affairs, and the size of most military organization, the segment approach appears to be a prudent kick-start. But, in a way, this incremental approach is not the end-state by itself. It merely streamlines the initial development, which could merge at a more advanced stage with the conventional approach to establish a truly optimal architectural framework for the organization.

Chapter 7 is devoted to a more complete elaboration of architecting for NCW success.

4. Research and Experimentation

The creation of an environment that supports innovation and experimentation is necessary to advance the NCW operational concepts. A conducive experimentation climate must comprise a central responsible agency to drive and co-ordinate the experimentation activities, the facilities to perform or play out the experiments, an institutionalized methodology to capture the learning experience, as well as a culture that encourages innovation and creativity.

The purpose of a central establishment is twin-fold. It must drive the focus of the NCW experimentation and research by setting both the near and long term goals. However, this must not stifle innovation and creativity. In that sense, its focus must be flexible and may gravitate based on experimentation or research outcome to where the promises are held. It must support both operationalization goals with fixed deliverables, as well as bold initiatives and innovative ideas which have higher failure but also higher potential gains.

The experimentation facilities must have an open architecture and ultra-configurability to incorporate new technologies and operational concepts. It must not be just based on the current command and control setup, and risk putting ourselves in the current operating mindset. It must stimulate new business rules, new ways of command and control, and new work flow.

The experimentation methodology must be institutionalized to instill the discipline to extract lessons from the learning experience for the future. A closed-loop process must be established, else we may fall into the usual trap and failures of combat exercises, where the same lessons are re-learned year after year. The figure below depicts the Mission Capability Package methodology employed in the U.S. Armed Forces (US DoD, 2001). It is designed to bring a concept from infancy to maturity as fielded capability through the stages of concept development, concept refinement, and operational implementation. The process employs a series of analysis, modeling and simulation, demonstrations, experiments and exercises in a close-loop manner and examines a wide range of factors such as organizations, CONOPS/doctrine, Command arrangements, C4ISR Systems, Logistics, Weapons Systems, Training/education, and Personnel.

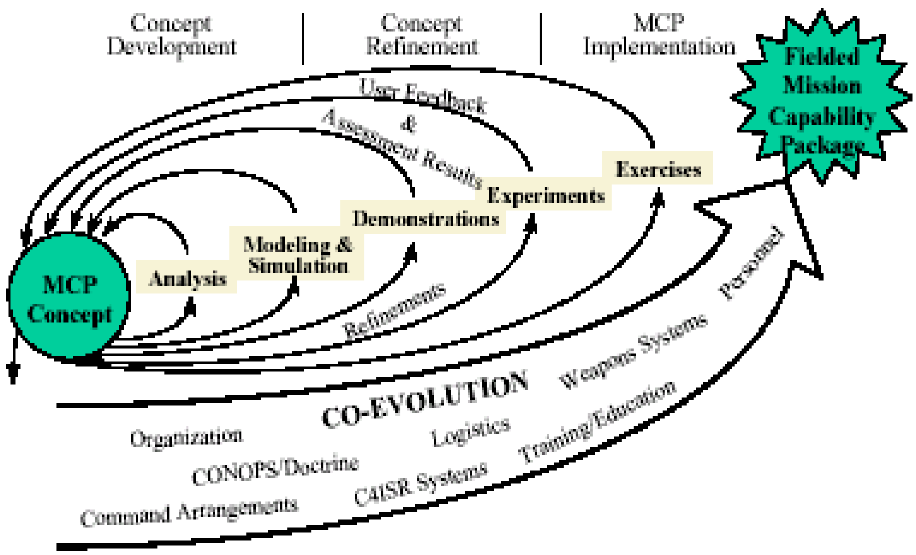

Figure 12. Mission Capability Package Process (From: U.S. DoD. July, 2001. *Network Centric Warfare - Report to Congress*.)

Culture is another critical element in conducting research and experimentation. Increasingly, NCW failures must be seen as a seed to fuel future success rather than as an end-state and a judgment by itself. A culture which encourages the generation of new ideas and creativity is critical to the success of the revolutionary changes that NCW is deemed to bring about.

5. Specifying and Measuring Performance

It is paramount to establish measurable NCW goals, to determine the value of various NCW investments and implementations to achieve its goals, and to determine progress using specific and non-ambiguous means. Essentially, a close-looped feedback system like the TQM process must be established so that the investment and implementation focus can continuously be fine-tuned towards NCW objectives. In measuring the NCW goals, one must differentiate between the functional requirements and the 'quality' or systems' attributes which are the outcome desired at the end of the value chain. There are a number of methods or metrics for the evaluation of command and control found in some of the current literatures, a few of them are highlighted below:

a. Measures of Merit (Alberts et al.,1999)

In the CCRP publication "Network Centric Warfare: Developing and Leveraging Information Superiority", a 'value-added' approach using a set of Measures of Merit (MoM) was suggested. This approach evaluates the contribution of C2 to mission performance by counting and weighting conflict results with and without the specific C2 enhancement. The MoM comprises five basic levels of measures (See Figure 12). At the first level, the performance of the C4ISR systems as federated into an infostructure is measured. This refers to the computation power and ability to transmit or distribute information, that is, connectivity and bandwidth. This level of measurement does not automatically translate into increased mission effectiveness. The other end of the measurement hierarchy is the measurement related directly to mission effectiveness or utility. For combat operations, common measures that have been employed have included attrition rates, FEBA movement, fratricide, leakage, and time to accomplish a given mission. A sixth level, Measures of Policy Effectiveness, was being contemplated. This level is intended to assess the contribution of a military operation that was part of a larger undertaking, such as Peace Operations. There may indeed be cases where "successful" military operations are not sufficient to achieve policy objectives. In these cases it is important to understand the limits of military power.

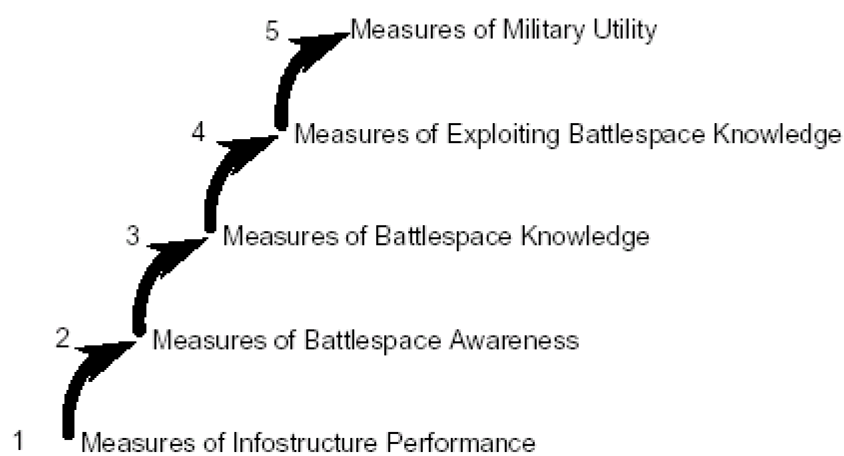

Figure 13. Hierarchy of Measures of Merit (From: Alberts, D.S., Garstka, J.J. & Stein, F.P. 1999. *Network Centric Warfare: Developing and Leveraging Information Superiority*. 2nd Edition. CCRP.)

Bjorklund noted in an earlier book (Bjorklund, 1995) on a similar approach that while such approach does not address the tempo and uncertainty attributes in winning or losing war, it does provide an insight into the quality of the decision process, and provide alternative options and improvements to the C2 processes.

b. Headquarters Effectiveness Assessment Tool (Hayes, 1999)

As its name implies, the Headquarters Effectiveness Assessment Tool (HEAT) is a method for evaluating the C2 effectiveness of a headquarters through its reactions to a changing warfare environment. HEAT assesses the overall effectiveness of decisions made and their implementation by subordinate headquarters by evaluating the various aspects of command and control, namely, the quality of the processes and the systems that support the processes, the quality of plans generated, and the quality of the directives issued to the forces to fulfill the plans. (Bjorklund, 1995). Like Alberts' MoM, HEAT serves as a good tool for evaluating incremental changes in C2 systems and 'before-and-after' training. However, it does not support 'two-sided wargaming' and hence is unable to assess the ability of commander and his staff in coping with uncertainty and battle tempo.

c. NATO Hierarchy for Metrics (Clark, 1999)

In Thea Cleark and Terry Moon's paper "Assessing the Military Worth of C4ISR", a hierarchy of metrics from the NATO Code of Best Practice [AC/243, 1999] was outlined. The metrics were adapted from the analysis framework, Modular Command and Control Evaluation Structure (MCES), developed through a series of MoM workshops sponsored by the Military Operations Research Society (MORS) for the measurement of performance and effectiveness within a conceptual model for C2 (Sweet, R. et al., 1985). Within MCES framework, MORS has developed a four-level hierarchy of measures comprising:

i. Measures of Force Effectiveness (MoFE) which focus on how a force performs its mission or the degree to which it meets its objectives. Prime examples are force and exchange (relative force losses) ratios.

ii. Measures of Effectiveness (MoE) which focus on the impact of C4ISR systems within an operational context. Examples could include communications survivability and resistance to countermeasures, ability to formulate and distribute plans or create a common operating picture.

iii. Measures of Performance (MoP) focusing on internal C4ISR system structure, characteristics and behavior. Examples would include sensor spatial coverage, network loading, target tracking and delays.

iv. Dimensional Parameters (DP) measure the properties or characteristics inherent in the physical C2 systems. Examples include bandwidth, signal to noise ratios, scan rate and field of view for sensors.

This hierarchy for metrics focuses essentially at the performance of command and control systems in terms of the system's ability to generate or collate information and provide it to the end-user in a timely manner. It offers a broad construct for developing approaches to measuring the worth of information in military operations and hence can be adapted to determine the effectiveness of command and control in NCW.

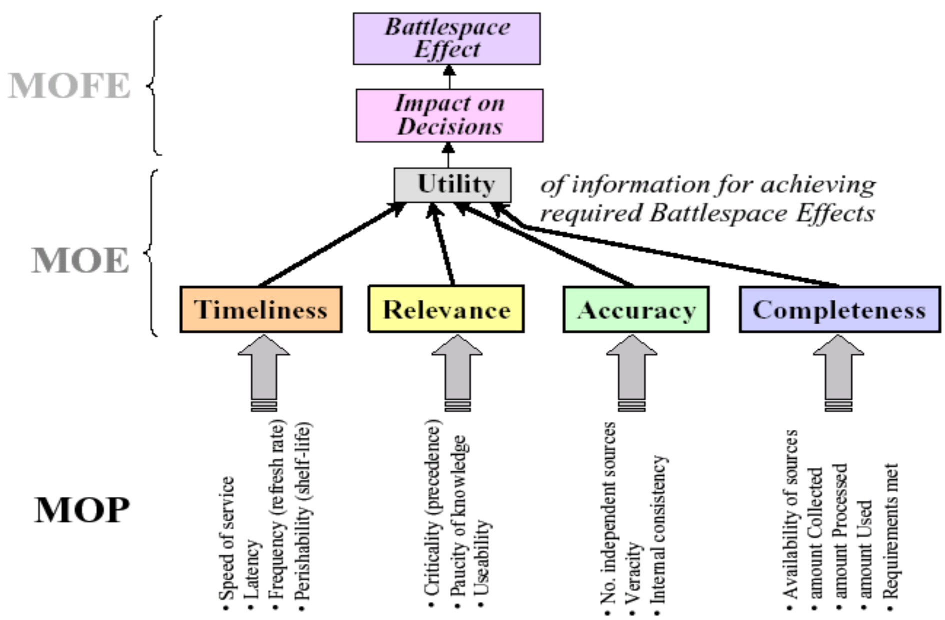

Figure 14. MORS Hierarchy of Metrics (From: Clark T & Moon T, 1999. "Assessing the Military Worth pf C4ISR Information. 7th International Command and Control Research and Technology Symposium).

While this hierarchy of metrics provided a comprehensive framework for C2 evaluation, there was no universal agreement on the meaning of the broad range of terms. For example, the measures of effectiveness (how well something contributes to its particular context) which is mainly a qualitative set of assessment, are very often confused with the quantitative measures of performance (how well the thing works by itself). (Bjorklund, 1995).

C. SUMMARY

It would be apparent by now, that the roadmap for NCW is not a linear process, one that we can mark out the phases clearly. Similar to the spiral software development process, it is cyclical or spiral, reiterative in nature. Continued evolution and efforts are required to shape and deliver the enhanced capability, towards the apex of maturity of the spiraling cone. However, the process is laden with great uncertainties and dynamics, coupled with the complexity of the task. Without unwavering leadership commitment and broad organizational acceptance, an effective framework to align the organization's resources and focus its efforts, a robust, seamless, and secured infostructure to kick-start the process, a closed-loop feedback and evaluation cycle, and an innovative and creative culture, the organization focus could go astray. The organization may cease to spiral upwards, but may either remain stagnant or spiral downwards as a result of depletive liability and wastages due to ineffective management and lack of focus.

VII. ARCHITECTING NCW

A. ARCHITECTURE AS AN APPROACH

The previous chapter outlined the roadmap of NCW, in which an NCW architecture is established as a key element and approach to achieving success in implementing NCW. This chapter will propose and elaborate on such an architectural framework to help further our goals in NCW. The architecting approach adopted here has its roots in software design and development. This approach over the years has been adapted and modified for various enterprise applications. But why an architectural approach and how it will bring us closer to the NCW goals?

Architecture is an abstraction of a system or systems (Clements et al., 2002). It represents systems in terms of abstract components that have externally visible properties and relationships. An NCW architecture will serve:

a. <u>As a Vehicle for Communication</u>. Being a common abstraction of a system, an architecture serves as a vehicle for communication among stakeholders by providing a common 'language'/platform that all stakeholders can understand and a 'blueprint' for the system that is to be built, modified, or analyzed. It also serves as a repository of information and references for system developments.

b. <u>As a Manifestation of the Earliest Design Decision</u>. Some of the earliest design decisions will eventually affect the flexibility and quality of outcome/product, as well as correspondence between the structure of the system/s and organization. Understanding and studying each of the earliest design decisions will avert disaster, or the need to undo the mistakes. This will mean greater productivity despite the time needed for a detailed architecting process.

c. <u>As a Reusable, Transferable Abstraction of a System</u>. Once established, an architecture may serve as a reusable basis for the entire family of systems and each of the systems can be built using common assets or components. This will serve to enhance inter-operability, as well as optimize resources and efforts in the development of another system within the family.

B. ARCHITECTURAL CONCEPT AND FRAMEWORK

The architecting concept proposed here is based on a three-level architecting process, namely, Envisionment, Family of Systems (FoS), and System development (See Table 1).

Level	Architecting Process	Purpose
1	Envisionment	Capability Overview
2	FoS Development	Architectural-based Design Product-line optimization
3	System Development	Project management/ Outcome

Table 1. Three-level Architecting Concept

The first level, Envisionment, captures the capability overview or vision of NCW. It entails various views, namely technology drivers/advancement, standardization forecast, threats forecast and other factors to determine and project the requisite capabilities and their required timeframe as shown in Fig. 15.

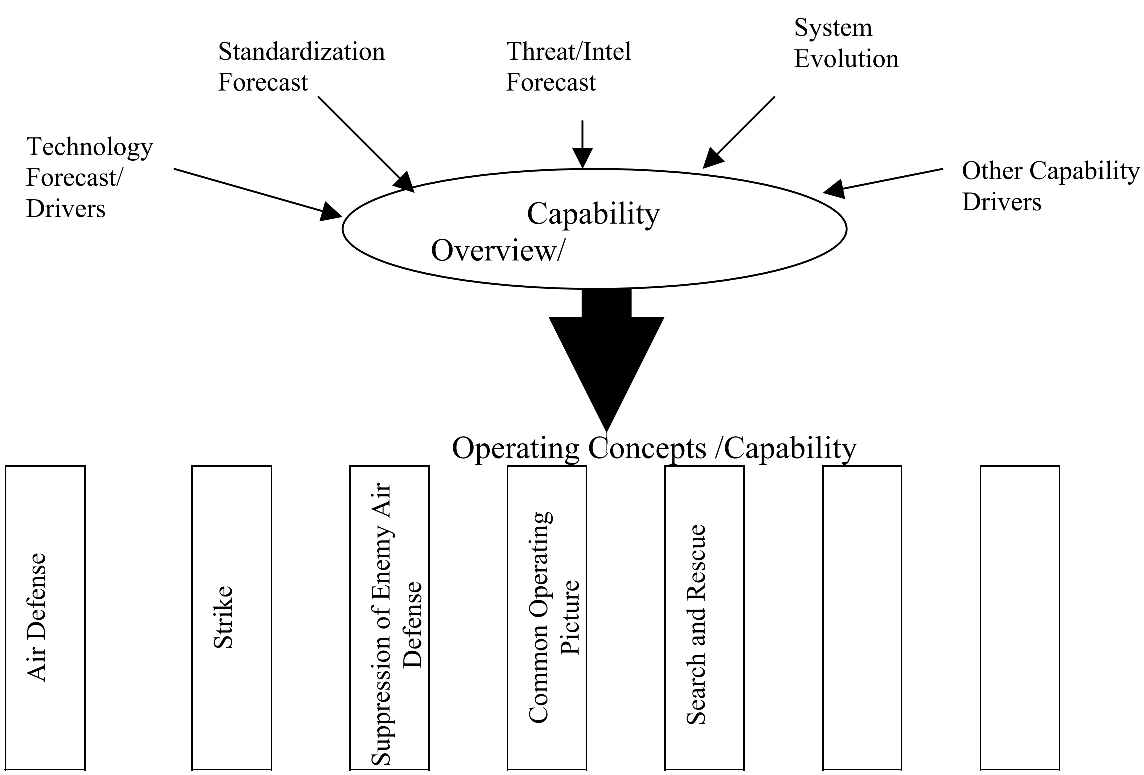

Figure 15. 1st Level of architecting : Envisionment

The second level, FoS development, is essentially a segmented approach cut along the key mission/warfare areas such as Precision Engagement, or even more specifically Air Defense, Strike, or Suppression of Enemy Air Defense (SEAD). The FoS development takes two axes of integration to ensure optimal alignment of the organizational resources to deliver effective combat prowess in a most resource effective and asset efficient way. It is integrated vertically to align performance (both functional requirement and quality attributes) to attain the mission goals. In addition, it is optimized horizontally across the common functional elements such as ISR, C2, logistics, to optimize developmental effort and share assets.

The architecting framework at the second level, FoS development, is built on a hybrid of both the Zachman's framework and the transformational framework of the National Institute of Standards and Technology (NIST) model. (CIO Council, 1999). See Figure 16.

	Data	Function	Network	People	Time	Motivation
Scope (Contextual)						
Enterprise Model (Conceptual)	Operational Information Exchange	Operational activity Model	Operational Node Connectivity	Organizational/ Command Relationships	Operational Event/Trace Specification	High-level Operational Concept
System Model (Logical)	System Data Exchange	Systems Functional View	System Connectivity View	System-user – location view	Operational Activities to System Traceability	High-level System View
Technology Model (Physical)	Data Modeling View	Code Blocks View	Interface View	Programmer responsibility chart	Concurrency View	-
Detailed Representation						

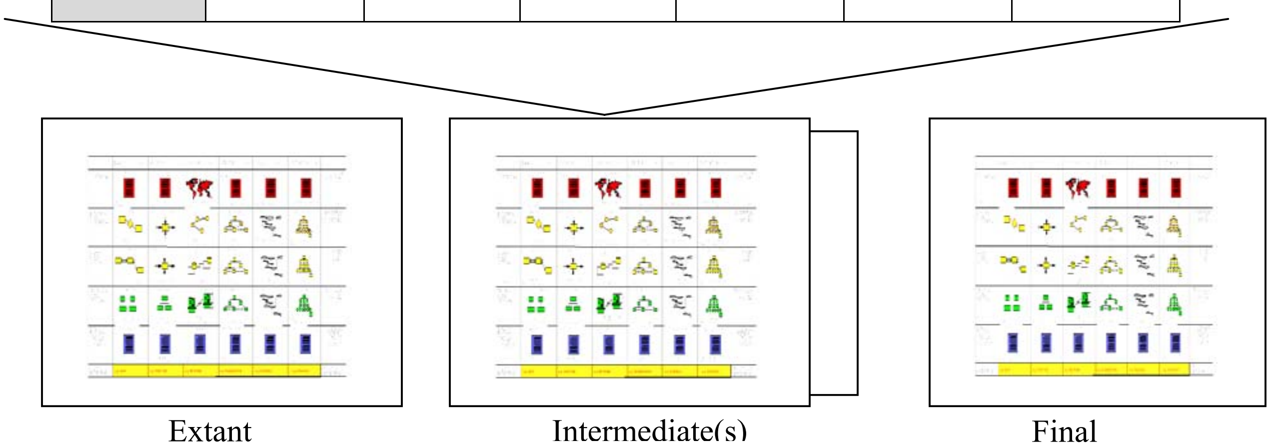

Figure 16. 2nd Level of architecting: FoS Development – Hybrid Framework

The Zachman's approach ensures a comprehensive coverage of the perspectives (row) and focuses (column), while the transformational framework provides a transitional roadmap of extant, intermediate and final views of the architectures. The latter is incorporated to facilitate a smoother implementation process, with the transitional timeframe and requirements considered upfront.

The last level of architecting, system development, provides architectural views of the individual systems similar to classic engineering approach, together with timeline and schedule to meet the envisioned capabilities.

Based on the architecture standards outlined in "Architecture Standards for Information System: a GST White Paper" (Percivall, 2002), the proposed architecture meets most, if not all, of the stipulated standards:

a. Maintenance Organization. This is not stated explicitly in the outline above as it would depend on the organization of the actual military establishment. It is expected that maintenance responsibility of the architecture must be formally assigned.

b. Architecting Products. This is defined based on the three levels of abstractions and views collected through the hybrid framework.

c. Architecting Process. The architecting process is defined. Based on the specific military establishment, a more detailed process can be outlined with the responsible agency designated.

d. Standards Category Model/Listing of Required Standards. This can be captured at the first level under the views for technology and standards forecasts.

e. Standards Development Process. This is not explicitly outlined in the architecture, but in the forecasting and adoption of standards, such a process must clearly exist or be developed.

C. FoS / PRODUCTION LINE METHODOLOGY

In his book "Design & Use of Software Architectures", Bosch asserted that opportunistic software reuse is not effective in practice (Bosch, 2000). Extrapolated from his experience, designing NCW systems, which is increasingly software-heavy in content, must be a planned and proactive effort. Bottom-up reuse, i.e., the composition of arbitrary components to construct systems, has not been effective in practice. A family of systems or product line approach is an important tenet of the proposed architectural approach as it is effective not only to foster resource sharing and reuse, but perhaps equally important, to ensure greater degree of inter-operability and expedient development of future NCW systems.

The design process of a product line architecture (Bosch, 2000) for NCW may consist of five main steps:

a. Feasibility Analysis. This first step is concerned with establishing the feasibility of framing an NCW capability/FoS within a production-line approach. Operational synergy and cost-effectiveness are two of the factors that would be considered during the analysis. The feasibility analysis also aims at determining the suitability of a evolutionary approach, that is, converting the legacy systems into a starting point for a FoS, or taking a revolutionary 'greenfield' approach.

b. Scoping. This step determines the product and the product features that may be included in the production line or FoS. It must decide on the tradeoff between extending the boundaries to include more products/features in the production line and its impact on the core performance or quality attributes of the individual product.

c. Product and feature planning. In order to ensure its existence is not short-lived, the product line must not focus on the current product and features but also plan for and anticipate future development and demands. This will make the incorporation of new products and features into the FoS easier.

d. Product line architectural design. This is the key step in the conception of the FoS/production line. In the process of designing the architecture, two critical artifacts, namely the production-line components and variability, must be derived. The components are the basic constituents of products in the FoS/production line. The variability of the components will determine the scope and extent of systems that could be accommodated in the same product line.

e. Component requirement specification and development. This step is concerned with the requirements specification and development of each of the components.

D. ARCHITECTURAL EVALUATION

In order to ensure the architecture serves its purpose, continual architectural evaluation must be conducted to periodically validate the direction and fine-tune efforts to best meet the needs, and to avert disaster by detecting early signs of it. Architecture Tradeoff Analysis Method (ATAM) is a comprehensive way to conduct such an evaluation. It comprises four main groups of activities (Clements et al., 2002):

a. Presentation. This is concerned with the exchanging and extracting of information of the nature of problems that the architecture is set out to address, and the key capability drivers (such as operational and technology). It aims to establish how the extant architecture addresses the problems and serves the driving factors of the capabilities.

b. Investigation and Analysis. This phase assesses the key quality attributes requirements vis-à-vis the architectural approaches. It identifies the architectural approach, generates the quality attribute utility tree through attribute characterization and instantiation, and then analyzes if the architecture is able to meet the performance requirements it sets out to meet. During this step, architectural risks, non-risks, sensitivity points and tradeoff points are identified.

c. Testing. This step involves activities to further test and validate if the architectural approach addresses the needs through scenario-based assessment. The stakeholders first brainstorm and collect a large set of scenarios which are then prioritized via a voting process. The high priority scenarios are then tested against the architecture to determine the robustness and effectiveness of the architecture. Additional concerns or assurances may be further consolidated.

d. Reporting. This involves the consolidation and reporting of the results of the evaluation.

Other evaluation methods exist such as the Software Architecture Analysis Method (SAAM), and Active Reviews for Intermediate Designs (ARID). They can also be selectively employed to serve our purpose. ATAM is a comprehensive evaluation methodology, but requires considerable stakeholder participation, which seems appropriate for major revolution/evolutionary changes such as NCW in our case where new capabilities or major modifications are undertaken. SAAM is a much simpler process which can be used during an afternoon to gain key architectural insights. It helps architects understand how their designs would react to evolutionary pressures that lead to modifications, as well as how well the designs provided the functionality demanded by their users. ARID is best suited for evaluating a partial design in its infancy and used to probe an architecture in ways hat the ATAM is not designed for.

E. SUMMARY

This chapter outlines a framework for developing NCW architectures, as well as the key steps in orchestrating FoS/product line architecture design and in conducting architecture evaluation. The proposed framework provides a comprehensive methodology and artifacts to address the anticipated needs of NCW. While a segmented approach is initiated along capability boundaries, it is important to note that the segment approach does not deliver the end-state or the final product. It is an initial approach to scope the problem within more manageable boundaries. Thus, it should not stop there. Once the segment architectures are fairly developed and manageable, the next stage of a holistic study, scrutinizing more on the cross-segment integration, should kick in. Another risk of the architectural approach outline is that because it is a comprehensive process and takes time and efforts, there is risk that people involved may replace architecting for delivery. The focus of the effort must emphasized on the delivery of enhanced capabilities. For that purpose, specific timelines may have to be set, and the architectural team must not have too long a time to come up with the perfect architecture. Rather, a spiral or evolutionary approach will better serve to continually advance the NCW goals. Importantly, the complexity of architecting for NCW should not be for the esoteric few, but rather the entire organization must be educated on the entire construction of the NCW architecture in order to achieve any possibility of success.

THIS PAGE INTENTIONALLY LEFT BLANK

VIII. CONCLUSION

A. THE NEW CIRCUS MAXIMUS

Advances in information technology have brought about revolutionary changes that pervade every corners of our life. This new *Circus Maximus* introduces new and revolutionary ways of conducting warfare – Network Centric Warfare which is premised on networked connectivity and information superiority. While initiated by technology, the new revolution is not just about technology application, it is about a new co-evolution of the entire span of military affairs, from organization, operational concepts, doctrine, training/education, to new military systems. The nature of this new information age warfare has provided great challenges in command and control. In this final chapter, some of these challenges and potential pitfalls are discussed.

B. C2 CHALLENGES

The nature of NCW imposes great challenges in the arena of command and control. First and foremost, command and control is becoming dramatically more complex as a result of compressed space and time, and the deluge of information. Yet, we are lagging behind in our capability to keep up with the increasing demands for information management, and more importantly, to transform this information to war-winning battle knowledge. Given the complex human behavior that drives the nature of command and control, our search for the Rosetta Stone of Measure of Effectiveness/Performance (MoE/MoP) of C2 also remains elusive.

1. New and Smarter Ways

Technology has compressed the space and time continuum, and political realities have collapsed the clear separations among the strategic, operational, and tactical levels by introducing more dynamic rules of engagement. The wired world has made the process non-linear, and we can no longer resolve problems effectively in a reductivist fashion – the top-down function–driven approach to break down a complex task to simple functional blocks. We must take into account greater number of entities, their interactions and mutual influences to determine the effects all at the same instant.

As a result of the increased tempo, warfare is no longer a series of static events, it is becoming seamlessly intertwined requiring greater integration and timely interactions between the heretofore disparate planning and execution processes. In order to exploit the opportunity provided by NCW to expedite the speed of command, we could no longer adhere strictly to the highly structured, cyclic, and time-table-driven C2 processes. A continuous process whereby combat entities self-synchronize to the mission objectives of the higher command seems to be the new order. However, in the process to optimize a myriad of requirements by transcending the highly institutionalized C2 cycle, we stand the risk of degrading to a state of laissez faire which the very existence of C2 cycle is intended to avoid. We need to devise adequate control mechanisms at the higher HQ to align the action of the combat entities while entrusting and allowing the combat entities the liberty and latitude of actions to self-synchronize to the mission objectives.

Technology has allowed us to act and respond quickly due to faster and wider bandwidth for communications. The wider connectivity allows command and control to span a wider area of responsibility – we are co-ordinating well beyond our optimal limit of 5-7 entities that human factor experts deemed that we are capable of. At the same time, as information sources and communication bandwidth grow, and our networks become more extensive, information that command and control processes have access to and manage is increasing by orders of magnitude. So, apart from speeding up tasks, we need to handle a exponentially increasing number of sources. Figure 17 highlights some of these fundamental problems based on data collected on accessing of information during the Bridge to Global (BTG) preparatory exercise. (Kemple, 1999).

Today, we rely on software development and information systems to provide us with the tools to deal with the information management problems. With NCW and the demands for greater inter-operability, software development is facing an uphill task of truly integrating the systems into the C2 process that infiltrates functional areas, acquisition processes, organizational structures and the mind-set of all involved. Yet, while our reliance on software increases, the results of software development have been dismaying. Over the years, less than 10% of the software systems have met the requirements, within budget and schedule. Breakthroughs in software engineering and development methodology are badly needed to provide us the effective tools to avert the increasingly serious problem of information overload.

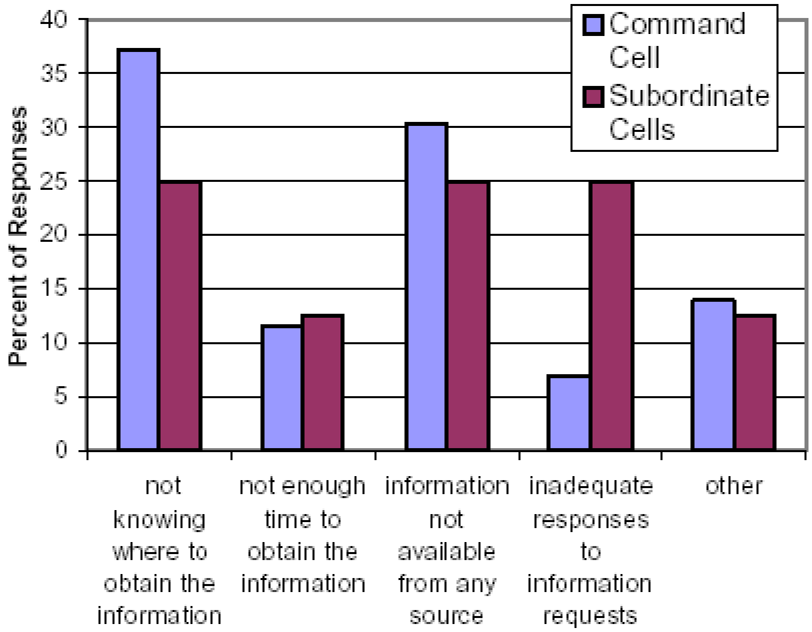

Figure 17. Barriers to Information Access (From: Kemple, W and others. 1999. *Building Adaptive Organizations: A Bridge from Basic Research to Operational Exercises*.)

Command and control has growth in complexity in order of magnitude over the years in terms of both breadth and depth. On top of that, the time available to perform the task is getting shorter. Software development on which we relied so heavily to generate the tools to address some of these problems is lagging seriously behind. Clearly, it is no longer adequate for us just to try harder. We cannot remain in our old mindset and thinking models. New and smarter ways of operating and overcoming the current predicament must be found.

2. Change Management

Change management has never been easy, particularly for a large organization. Even more so, when today's military organizations are faced with both a problem of misfit between the organization and operating philosophy, and continuous waves of disruptive innovations.

Since the Napoleonic era, the hierarchical nature of command and control has been the mainstay and de-facto organizational principle for military organization. The hierarchical structure facilitates task division, ensures accurate dissemination of orders and plans, and supervises execution. In fact, the success of command and control is sometimes deemed as the ability of the commander to exercise tight control and supervision to focus war efforts and orchestrate battle. Yet, the benefits offered by NCW is inherently at odds with the hierarchical structure. The dramatic expediting of the speed of command depends on simultaneous and instantaneous dissemination of information and the by-passing of organization layers to achieve the improved responsiveness. This has created many contentious issues and contradictions such as the rationale for central planning, autonomy of combat entities and so on.

Clearly, key aspects and attributes of Network Centric Warfare are fundamentally disruptive in nature. Disruptive innovation is about bringing to fruition ideas or products that are very different from the status quo. This form of innovation which is associated with revolutionary changes usually brings about great uncertainties and changes, which in turn generate more resistance and impediments for change. In fact, the competencies that organizations develop in becoming successful at sustaining innovations (improving performance of existing products or services) create impediments to disruptive innovation (U.S. DoD, 2001). For example, information sharing and collaboration disrupt existing organizational decision making processes, authorities, and values based on information compartmentalization, centralized planning, and chain-of-command. Allocating resources to the networking of the force, potentially at the expense of platform and weapon acquisition and "modernization," threatens existing "platform-centric" power structures.

Each new revolution in military affairs brings about a new set of values and thinking. To successfully bring about the new revolution and change, it is fundamental to transform the inherent organization culture and mindset, which many times proves to be most difficult and protracted. The recognition that this 'inner' change must take place is a start to grapple with the issues, which no amount of hardware and technology can replace.

3. The Search for the Rosetta Stone

Since the 1970s, the search for an objective solution in measuring the performance of command and control has been on. The efforts have intensified over the years, as command and control has emerged from being a peripheral function to become a critical link and force multiplier of capabilities. However, the search for this Rosetta stone has so far proved to be elusive. A key problem is the difficulty in defining the value of information and the contributing factors to the success of C2 (Bjorklund, 1995). The complexity of military organization with its many interacting and mutually influencing entities, and its dynamic and uncertain operating environment largely contributes to it. As a result, the commander's decisions do not always determine the results of combat, and the outcome varies greatly with changes in the situation. Even when the commander's decision has significant bearing on the outcome, the random nature of combat means that the commander is only influencing the probability of outcomes rather than influencing the outcome themselves. The unstable and random nature of combat also make predictions difficult. Moreover, the complex human psychological make-up clouds the problem. It is almost impossible to evaluate objectively psychological (and even emotional) preferences for C2.

The ability to measure the effectiveness/performance of C2 is critical, without it we cannot focus our C2 investment and efforts. Yet, after all these years of effort, the Rosetta stone is still waiting to be discovered.

C. AVOIDING THE PITFALLS

There is no absence of exaggerated claims and misinformation clouding the concept of NCW. It is also important to note some of the apparent lessons and limitations of NCW to avoid the major pitfalls on our road towards NCW.

1. More Is Not Always Better

Information and networking are the twin engines for NCW. However, more does not always means merrier. Judicious operational judgment and financial prudence must prevail in proliferating and networking the forces. More information is not always better. Dissemination of information does not guarantee assimilation. Excessive information processing will indeed overload, and worse, incapacitate the ability to access more critical information. More connectivity is not always better. More nodes out there means more nodes to maintain, protect and secure. Without serving a purpose, additional connectivity will only be a cost liability. In fact, Metcalfe's law does not guarantee that increasing connectivity automatically translates to operational effectiveness. The law merely relates to potential gains. In establishing the information and connectivity needs, the organization, doctrine, operating concept, training and all other key elements must be considered.

2. The Myth of Reducing Cost

Cost reduction, whether in actual capital investment or recurring IT cost, has often been used to justify the pursuit for NCW. However, such optimism may be misleading. As an analogy, the pursuit for Enterprise Resource Planning (ERP) in the business/commercial sector has been going on for years. Yet, few companies have made that giant leap successfully, and even fewer, if any, have done it and achieved cost saving. This is not to dispute the justification for NCW. In fact, it is probably true that there are no other alternatives to NCW in the information age. There may be no solution more cost-effective than NCW. But, that is not the same as saying that it would actually lead to saving or reduction in current cost. With the increasing dependency and growing complexity in IT, the cost will only follow the upward trend. But with astute operational judgment and financial prudence, we may hope to reduce wastage and stretch the dollars. Take the PC as an example; while memory and hardware have reduced in cost, our insatiable demands for higher computing power and greater processing speed have not necessarily reduced the price of a home PC.

3. The Myth of Global Situational Awareness

NCW has promised the distribution of a common and global situational awareness. However, it has reduced the notion of situational awareness to the common battlespace picture that is being proliferated. This simplistic approach ignores the complexity of modern warfare, the professional training and experience needed to interpret the information, and the key process of converting information to war-winning battle knowledge. Such a notion is dangerous as it trivializes the importance of training and experience, and encourages reckless network behavior such as excessive information forwarding. Information needs to be managed. It needs to be interpreted and assimilated so as to be useful in decision making.

D. SUMMARY

NCW offers great opportunities, the ability to speed up command, the ultimate mobility that replaces movement of troops with movement of information, the precise stand-off targeting, and so on. While we have yet to realize its full potential, we are beginning to have a glimpse of the promises held by NCW in some of the recent operations and campaigns. The road leading to NCW is laden with daunting challenges, though we are beginning to understand some of them. NCW is not just a revolution of technology, it requires continuous co-evolution of the full spectrum of elements in military affairs to bring about the dramatic increase in combat prowess. We need to transcend and integrate across a number of dimensions including time, geography, platform, and functions. We need to manage the transformation through a methodical enterprise framework to focus our efforts and align our resources. We need an open and learning environment to experiment and develop new and smarter ways of operation. We need broad acceptance and unwavering commitment to stay the course for the long haul.

There is neither a magic panacea to overcome these problems nor a flying carpet to bring us to the end of the journey instantaneously. The secret to arriving at the destination early is to embark on the journey today!

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF REFERENCES

Alberts, D.S., Garstka, J.J. & Stein, F.P. (1999). "Network Centric Warfare: Developing and Leveraging Information Superiority." 2nd Edition. *C4ISR Cooperative Research Program (CCRP)*.

Alberts, D.S., Garstka, J.J. (Dec 14, 1999). "Information Superiority & Network Centric Warfare.". Briefing Slides from "The Information Warfare Site". {http://www.iwar.org.uk/iwar/resources/info-superiority1999/}.

Barnett, Thomas P M. (1999). "The Seven Deadly Sins of Network-Centric Warfare". United States Naval Institutes. January 1999. ProQuest. {http://proquest.umi.com/pqdweb}.

Bjorklund, Raymond C., (1995). "The Dollars and Sense of Command and Control". National Defense University Press. Washington D.C.

Bond, W.L. (BG). (1998). "Military CIS '98". Briefing to Dr. Jacques Gansler, USD (A&T), at the Pentagon, Arlington, VA, on April 20, 1998.

Bosch, Jan. (2000). "Design & Use of Software Architectures: Adopting and evolving a product-line approach". Addison Wesley.

Burton, R. M., Obel, B. (1995). "Strategic Organizational Diagnosis and Design: Developing theory for Application". Kluwer Academic Publishers.

Cebrowski, A.K. & Garstka, J..J. (January 1998). " Network-centric warfare: Its origin and future." *United States Naval Institute Proceedings*, 124(1), pp.28-35.

CIO Council. (Sep 1999). "Federal Enterprise Architectural Framework". Version 1.1. *The Chief Information Officers Council.*

Clark, Thea & Moon, Terry. (1999). "Assessing the Military Worth of C4ISR Information". *7th International Command and Control Research and Technology Symposium.*

Clark, Wesley U.S. General (Retd). (2001). "Waging Modern War: Bosnia, Kosovo, and the Future of Combat. New York: Public Affairs.

Clements, P., Kazman R. & Klein, M. (2002). "Evaluating Software Architecture: Methods and Case Studies". Addison Wesley.

Fassbender, H. & Stein W. (2004). "Surveying Research and Development Approaches in the Field of Command and Control Information Systems: A Method-Oriented Perspective". {http:\/\/www.dodccrp.org/Proceedngs/DOCS/wcd00000/wcd00070.htm}.

Fitzsmonds, James R. (1998). "The Cultural Challenge of Information Technology". *United States War College Review*, Summer 1998.

Hayes, Richard E. and others. (Sep, 2003). "Headquarters Effectiveness Assessment Tool (HEAT)". Evidence Based Research Inc.

Hayes-Roth, Frederick. (September, 2003). "Architecture, Interoperability, and Information Superiority". Naval Postgraduate School.

Horner, Charles A., General - USAF (Ret.). (December 1998). "Comments on Expeditionary Force Experiment '98," C2 Earlybird: Special Edition EFX '98 Lessons Learned 1: Special Ed.1

Joint Publication 1-02. (1998). "Department of Defense Dictionary of Military and Associated Terms". Washington D.C.

Keeter, Hunter. (Apr 2003). "Cebrowski: Iraq Shows Network Centric Warfare Implementation". *Defense Daily.*

Kemple, W.G., Kleinman, D.L., Hess, K.P., Hess, S.M., Hocevar, S.P., Entin, E.E., Hutchins, S.G., Serfaty, D. (1999). "Buidling Adaptive Organizations: A Bridge from Basic Research to Operational Exercises".

Khoo, Jimmy B.G. (2003). "Eight Big Reasons Why Transformation Is Not For The SAF." Pointer V29 N3 (Jul – Sep 2003).

Kleinman, D.L., Levchuk, G.M., Meirina, C., Pattipati, K.R. (2001). "Design and Analysis of Robust and Adaptive Organization". 2001 Command and Control Research and technology Symposium (A2C2 session)

Kirzl, Jojn E., (1999). "Command and Control Evaluation in the Information Age". Studies, analysis and Simulation Pane (SAS) 1999 Symposium on Modeling and Analysis of Command and Control. Evidence Based Research, Inc. {http://www.ebrinc.com/ebr/pubs/kirzl/Kirzl_final.htm}.

Logan, B. C. (Aug 2003). "Technical Reference Model for Network Centric Operations". Crosstalk-The Journal of Defense Software Engineering.

McGray, D. (Feb 2003). "The Marshall Plan", Wired Magazine Issue 11.2.

Naval War College. (1998).Global 98: Network-Centric Warfare, Newport.

Pascale Combelle Siegel. (1998). "Target Bosnis: Integrating Information Activities in Peace Operations". Washington D.C. National Defense University Press.

Percivall, Goerge. (Jun 2002). “Architecture Standards For Information Systems – A GST White Paper”. Version 0.2. *Global Science and Technology, Inc.*

Robert C. Rubel. “War-gaming Network-Centric Warfare,” *Naval War College Review* 54, no.2 (Spring2001): 65-66.

Schroeder, M. C. Lt Comd USN. (Feb 2001). "The Issues of Command and Control in Network Centric Systems". Naval War College. Newport R.I.

Senge, Peter. (1990). “The Fifth Discipline: The Art and Practice of the Learning Organization”. 1st Ed.

Smith, E. A., (2001). “Network-Centric Warfare: What’s the Point?”, *Naval War College Review* 54, no.1(Winter 2001): 60-61.

Stein, Fred P. (2003). "Observations on the Emergence of Network Centric Warfare". Evidence Based Research Inc. {http://www.dodccrp.org/steinncw.htm/}.

Sweet, R., Metersky, M., & Sovereign, M. (1985). “Command and Control Evaluation Workshop”. Military Operations Research Society (MORS) C2 MoCE Workshop. Monterey , CA: Naval Postgraduate School.

Tirpak, J.A. (Oct 1987). “Deliberate Force”. Air Force 80:10.

U.S. Army. (Dec, 2000). “The Infantry Battalion”. Field Manual FM7-20.

U.S. Department of Defense. (July, 2001).”Network Centric Warfare”. Report to Congress. {http://wwww.c3i.osd.mil/NCW/}

U.S. Department of State Bureau of Verification and Compliance. (June 2002). “World Military Expenditures and Arms Transfer 1999-2000”. US Government Printing Office.

U.S. Joint Chiefs of Staff. (2000). “Joint Vision 2020”. Washington, D.C.

U.S. Joint Chiefs of Staff. (1991). “Joint Warfare of the U.S. Armed Forces (Joint Pub 1)”. Washington D.C.

U.S. Joint Chiefs of Staff. (Feb., 1995). “Doctrine for Joint Operations (Joint Pub 3-0)”. Washington D.C.

Van Creveld, M. L. (1985). “Command in War”. Cambridge, Mass. : Harvard University Press.

Zachery, Martin. (March 2000). "An Emerging Concept". Marine Corps Gazette. Lkd, ProQuest. {http://proquest.umi.com/pqweb}.

Zimmermann, John D. (Feb, 2000). "Command and Control in a Network Centric Environment." JMO Research Paper, Naval War College.

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California

3. Lim, Soon-Chia
   Republic of Singapore