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# Command and Control in the Information Age: A Case Study of a Representative Air Power Command and Control Node

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**COMMAND AND CONTROL IN THE INFORMATION AGE: A CASE STUDY OF A REPRESENTATIVE AIR POWER COMMAND AND CONTROL NODE**

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## ABSTRACT


COMMAND AND CONTROL IN THE INFORMATION AGE: A CASE STUDY OF A REPRESENTATIVE AIR POWER COMMAND AND CONTROL NODE

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As operations command structures change, it is important to be able to explore and understand their fundamental nature; researchers should unearth the gestalt nature of the operational node. The organizational structure and the infrastructure can significantly affect overall command and control (C2) performance. Thus, it is necessary to develop understanding of effectiveness of the technical network and the people using the system as a whole.

The purpose of this research is to conduct an analysis of a representative Air Power Operational C2 node, create and use a repeatable method, and present the results as a case study to elicit fundamental understanding. I posit that there is a recognizable (and discoverable) relationship between the social (human) network and technical supporting network. Examining the system under change can result in an understanding of this relationship. In this work, I enhanced an existing simulation tool to investigate the effects of organizational structure on task effectiveness. The primary research question examined is how a representative AOC system changes varying noise and system fragmentation when operating in two different organizational constructs.

Network-Enabled Capability (as the term is used in NATO), Network Centric Operations, or Edge Organizations, is a core C2 transformation predicated upon a set of

network-centric tenets. These tenets form the intellectual foundation for ongoing transformations. The secondary research question is to determine if these tenets are unbound, and what elucidation results if they are not.

This research produces four significant contributions to Operational Command and Control and Engineering Management disciplines. First, I combined social networking theory and information theory into a single lens for evaluation. By using this new concept, I will be able to accomplish a quantitative evaluation by something other than mission treads, field exercise, historical evaluation, or actual combat. Second, I used both information theory and social networking concepts in a non-traditional setting. Third, I hope this research will start the process required to gain the knowledge to achieve some sort of future C2 structure. Fourth, this research suggests directions for future research to enhance understanding of core Operational Command and Control concepts.

This dissertation is dedicated to my wife, Megan.

Without her love, support, belief in me (and sometimes pushing),

I would never have finished this endeavor.

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Two people require special recognition:

1) I want to thank Amy Soper. She gave me a ‘voice" to talk publicly about my passion - Operational Command and Control.

2) I want to thank Mary Rudy. She taught me ELICIT and worked patiently with me to get the model extended to meet an operational need.

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# CHAPTER ONE - INTRODUCTION

A precise answer to the wrong question can be more harmful than an eclectic answer to the right question. The wrong question to ask about the Command and Control (C2) domain is how to best line up all the computer systems and applications to achieve the reality promised in the marketing phrase, 'the right information, at the time, and at the right location in the right format.' This phrase is misleading on three counts: the sales pitch defines a priori information as equivalent to a posteriori information; this carnival worker's call implies global data coupling in which all information has the same pedigree (level of validity, level of security, level of availability, level reciprocity, etc.); and that data will be shared ubiquitously. Information age warfare will be different from industrial age warfare:

> The war, as any other human activity, is a product of its age, its weapons and strategies permanently evolved in the same time with the technology development. The future war in the "information age" embeds the unique characteristics of this period, thus being different than the other types of war previously conducted and affecting the operation capabilities and the nature of the conflict environment. (OPERAN, 2012)

The difference may be as great or greater than the difference between agrarian age warfare and industrial age warfare. Air power and ground power have combined to achieve the operational objectives in the last five US wars. Command and Control is the glue that holds it all together. The better research question is: how should C2 be studied for fundamental understanding?

An actual air power C2 system exists only when engaging an adversary. The actual system is a combination of the people and infrastructure in place accomplishing an actual military mission. An Air Operations Center (AOC) is a Knowledge Management C2 entity in which humans either analyze or synthesize inflowing data. Data flows into the organizations, which are an abstraction of the actual world, and requires processing in such a manner that output influences the actual world. I posit there is a recognizable (and discoverable) relationship between the social network and technical network operating in an AOC. By examining the system under change, that relationship can become understandable. Changes in the technical network will result in changes in the social network, and changes in the social network will result in a measurable difference in utilization of the technical network,

I propose that, in the AOC, two separate networks exist with limited touch points. One set of connections is a technical network that conveys data, and the other is a human command network that manipulates data, transforms it into information, and produces decisions that result in output. To achieve an epistemic understanding of the totality of the node, both networks require harmonization of understanding by determining how an action in one network affects the other network. If the AOC node is understandable, then there is a high probability that the knowledge can extend to other organizations. A classic scientific research approach implies qualitative research as the prerequisite needed to accomplish quantitative evaluation; I am pursuing initial qualitative research. Exploratory case study research such as this study is not a random sampling of a given system. That is an assertion of major researchers in case studies to include Yin (2003) and Stake (1995). This case is designed to maximize knowledge acquisition during the time period, and within the given resource constraints. Exploratory case studies have been used by others, such as the 1997 RAND Weapons Mixed and Exploratory Analysis by Arthur Brookes, Steve Bankes, and Bart Bennett. In the RAND introduction, they define an exploratory analysis as a method to help comprehend complex systems such as combat models, which may have imperfectly known parameters, decisions, and measures of effectiveness.

An important determination is to define the unique contributions "C2 in the Information Age" brings to the plethora of C2 thought. To start that determination, I segregate seminal authors in both IT and Social Networking into two schools of thought. The IT school of thought deals more with machine themes and consists of authors such as: Shannon (1949), Ashby (1948), Beer (1985), Conant (1976), Sommerhoff (1950), Brillouin (1962), Nørretranders (1991), and Waelchli (1989). Some of the authors lean deeper towards machined themes than others, but as a group, they all lean away from human/organizational themes. The other school of contemplative activity consists of authors that are concerned with human/organizational themes, such as Mathieu (2000), Carley (1997); Klimoski and Mohammed (1994), Sonnenwald and Pierce (1998), Kaplan (1980), Graham (2004), Barnes (1954), Hanneman (2005), Granovetter (1973); Milgram (1967). Between these giant schools of thought there is a much smaller, often more disjointed dojo of authors that write about themes that bind both mechanical and human themes under a widely chassed net of differing perspectives. These are authors like Bharadwaj andKonsynski (1999) Brynjolfsson and Hitt (2000); Aral and Weill (2007), Hinds and Kiesler (2002), Cyert and March (1963), Arrow (1962), Stiglitz (2000), and Joslyn and Rocha (2000). I have to cast my lot with this third group of ronin.

Defining into which daimyo of thought I should bin this dissertation does not define the unique contribution of this work. As Sutton (1986) points out, a common definition of C2 will most likely never congeal. Just because something does not carry a universally recognized moniker does not mean it cannot be thought about or measured, or made better. Between C2 theory and C2 operations stands C2 Systems. According to Maykish (2014), "C2 history shows that C2 theorists navigated megatrend-type changes while gaining insight into C2 fundamentals at the same time." His supposition results in the following chart:

| *Stages of Modern C2* | *Waypoints* | *Navigating Megatrends* | *Discovering Fundamentals* | *Key C2 Result* |
|---|---|---|---|---|
| Stage 1 | Napoleon (France) | The looming of industrial-style warfare | Expanding C2 art in the single leader, single battlefield model | Pushed C2 art |
| Stage 2 | Moltke (Prussia) | Transportation and communication revolutions | A "system of expedients" over multiple battlefields | Envisioned systems warfare |
| Stage 3 | Tukhachevskii (Russia) | New operational level of war and the front edge of the aviation age | "Expedients" refined into clear C2 subfunctions | Made C2 tangible |
| Stage 4 | Dowding (United Kingdom) | Range and speed of the aviation era in full swing with increasing battlespace depths | Sophisticated SA feeds and teams of controllers performing C2 subfunctions form an adaptive system for defense | Systematized feeds and teams |
| Stage 5 | Boyd (America) | Computer-based data management and the front edge of the information age | Transferring competition fundamentals into a system of "insight" | Incorporated competition fundamentals |
| Stage 6 | Uncertain | Network-centric C2 operations and cyber warfare | Uncertain | Uncertain |

*Figure 1.* Modification of Maykish (2014)

The unique contribution of this paper is to begin to sort through the "Uncertain" that currently defines Maykish's Stage 6 by pushing against the walls of darkness in which humanity eternally struggles.

## 1.1 A BRIEF HISTORY

Operational air power is executing targeting, from the air, over a broad time and space. The implementation of an Air Tasking Order (ATO) will most likely accomplish Air Power either in an industrial age model or in an information age model. The purpose of the ATO and Air Control Order (ACO), as defined Joint Publication 1-02 (2010), is:

> 'A method used to task and disseminate to components, subordinate units, and command and control agencies projected sorties, capabilities and/or forces to targets and specific missions. (p.11)' while and ACO is 'An order implementing the airspace control plan that provides the details of the approved requests for airspace coordinating measures. (p. 9)

To understand how the technical network and human network overlap in the execution of operational Air Power Command and Control, we should understand the history of the USMTF ATO production tool. The ATO message has two sub-sets: Mission Data Lines (MSNDAT) and Special Operation Instructions (SPINS). Traditionally, the AOC staff creates MSNDAT, and mostly Air Force Forces (AFFOR) staff correlates much of the information required for SPINS. Both sets of information and the information in the ACO message are required to execute combat air power.

Automated building of the ATO message started with a Disk Operating System program, Frag Works, which ran on a 286 PC in the early 1980s. The program allowed one person (generally a clerk-typist) to fill blank fields in the USMTF message (today, we would call this message a text or flat file). A group of experts performed all planning (including sortie deconfliction and tanker scheduling) by hand calculation or using other stand-alone computer systems.

Today (the year 2014), a Theater Air Planner (TAP) produces the ATO message, but the expert creators of the ATO no longer use the TAP applications as their primary input tool; they use Master Air Attack Planning Tool Kit (MAAPTK). MAAPTK was developed as a better graphical interface to build missions for inclusion into the ATO. MAAPTK enables planners to visualize and generate missions quickly and accurately. Expert planners see information on tables with timelines, maps, and graphs so that they can quickly understand the essential parts of the planning problem. Additionally, they can create their missions and packages using a simple drag-and-drop action. MAAPTK significantly streamlines the total MAAP/ATO production process and reduces some manpower in the AOC.

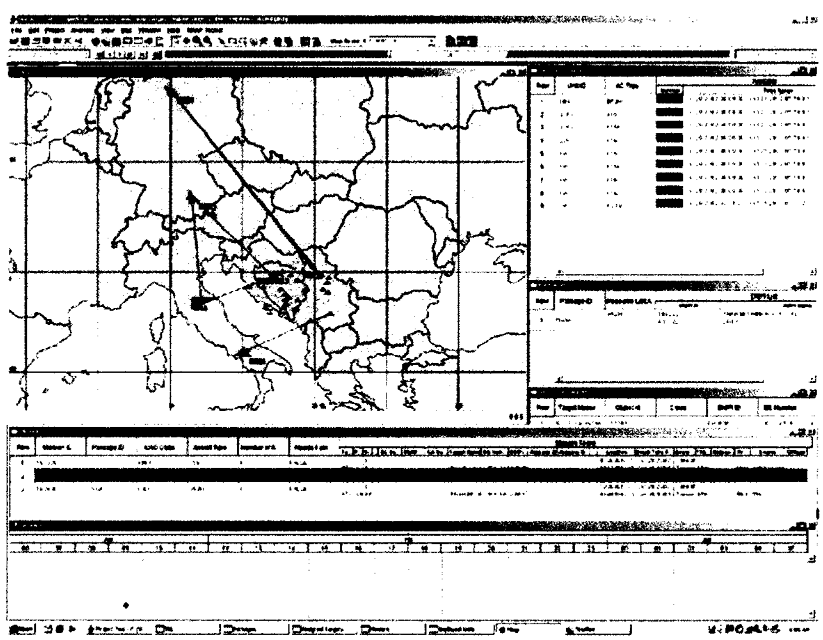


*Figure 2.* Example Derived from MAAPTK User Manual

In light of this history, it is clear that an effective Operational Airpower node like the AOC must look well beyond the simple design philosophy that resulted in the creation of the current USMTF message. To continue to achieve leadership goals, we need to understand and discover core C2 concepts.

## 1.2 STATEMENT OF THE PROBLEM

As previously stated, in any Command and Control (C2) node including an Air Operations Center (AOC), there are two separate networks that have limited touch points. Nevertheless, in an information age, these networks must work together to be efficient.

In most cases, people dealing with events occurring closer to "now" will synthesize more and analyze less. In effect, the internal human system and the external system become one homogeneous mass. One of the difficulties swiftly encountered in researching C2 is high variability in the quality of literature about the subject, as the writings express the authors' cogitative concepts about a wide range of subjects. Many writings are articulated with thoughts that are an 'inch deep and a mile wide' in quantitative or qualitative facts, leading to the near impossibility of repeatability as validation. Therefore, the purpose of this research is to conduct a *comparison* analysis of a representative Air Power Operational C2 node using a case study design to elicit fundamental understanding. The goal of the research is to face the future and compare a representative C2 node to a differently constructed C2 node, and not to compare the results to an actual C2 node using historical evidence.

## 1.3 PURPOSE OF THE STUDY AND RESEARCH QUESTIONS

Current AOC organizational realities have: (1) a high degree of technological complexity required to manage massive amounts of data; (2) non-linear knowledge intensive work; (3) changing battle space influencing work system effectiveness; and (4) turbulent—uncertain and rapidly changing—mission requirements.

Any electronically stored, transmitted, or recorded data is neither information nor knowledge. Humans must give these mathematically defined and physically manipulated voltages context. At the same time, the language of data, information, and knowledge can convey an appropriate extraction of reality. By using language to transform data into an understanding of reality any military corps or above organization, such as an AOC, is in reality a knowledge management entity. The AOC is not the only command node in the human control that relies on an artificial representation of reality to make decisions and provide life changing outputs. The operations center of a Nuclear Power Plant (NPP) has similarities with the Combat Operation divisions of an AOC. Information theory work has been accomplished in conjunction with NPPs using Conant's Model as a tool for describing human information processing (Kim, Soong, & Poong, 2003). Using a cross discipline tool like information flow theory to evaluate the AOC can provide a proven quantitative measure. Replicating an actual theater technical milieu, if theoretically possible, would be cost prohibitive (and most likely the adversary would not volunteer to participate). Incorporating a measure (Conant's Model) for information processes may achieve the goal of repeatability. More importantly, a quantitative measure of information processing provides a hope of minimizing the human variable by putting the human in the background.

Social networking theory (SNT) is one of the few theories that can apply to both small groups and planet-sized groups. Any network describes some type of relationship. The simplest of networks has two nodes tied by a link. The node is the end point, and the link is what ties them together. [Social] Network analysis has grown from the esoteric interest of a few mathematically inclined sociologists to a legitimate mainstream perspective. Harrison White and Affiliates, who also developed a formal apparatus for thinking about and analyzing social structure as networks (Nohria, 1998), spearheaded social networking development in the 1970s. Social network analysis (SNA) is an appropriate tool to evaluate the human networking side of C2. Social network theory looks at relationships in terms of links and nodes. Nodes are the individuals, and links are a relationship between the individuals. There are many different ways people can be linked (face-to-face, e-mail, text chat, phone, meetings, etc.), and each interaction has an effect on the whole. Those interactions will be instantaneous (shared) or asymmetric (posted/pulled). Social networking proposes individuals are less important than their relationships. Those relationships define a structure that can be studied (Barnes, 1954; Granovetter, 1973; Milgram, 1967).

The origins of information theory (IT) begin with C.E. Shannon and his article, "A Mathematical Theory of Communication," published in 1948. Shannon proposed entropy as a measure of information, choice, and uncertainty. Entropy was a measure in such diverse communities such as biology, decision theory, and thermodynamics. Information relates to uncertainty, which can be given as a function. The amount of information and bits, is equal to the base 2 logarithm of the inverse of the probability:

$$H_i = \text{Log}_2 1/P_i \qquad (1)$$

$H_i$ is the amount of information and $P_i$ is the probability of occurrence of $i$. Using a formal mathematical construct for information, I can remove the human subject constraint concerning any "value" of one generic informational blob as compared to another.

Working within the brackets of SNT and IT, the first research question is: Can a framework be constructed using Social Networking Theory and Information Theory to evaluate a representative Air Power C2 node?

The year 2009 was pivotal in Air Force history. It was the first year the Service bought more Unmanned Aerial Vehicles (UAVs) and trained more pilots to fly them than traditional aircraft. If warfighters flying combat vehicles are not required to move into a forward Area of Responsibility (AoR), why should it be necessary to send a large AOC forward to provide the C2? By viewing a single representative C2 node stereoscopically using a formal case study method, this single emulation could be a step toward an epistemic understanding of a distributed/federated C2 structure.

The nature of war historically adapts to the technology available. Metaphorically, ancient military operations were more like solid mechanics, whereas fluid mechanics could well represent industrial age combat. The term that best applies to knowledge age combat is 'Cloud' centric, in which a small world of knowledge drives the understanding of truth. Therefore, the last research question is to determine if the current tents of network-centric warfare are unbound. A diagram of the relationship between the purpose and the research questions would be as follows:

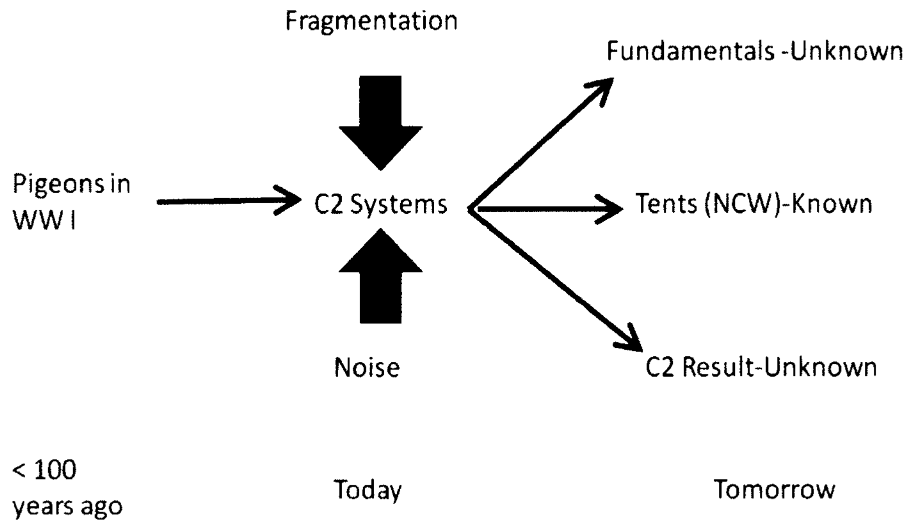



*Figure 3.* Relationship between Purpose and Question

## 1.4 NATURE OF THE STUDY

This case study is to see how the AOC C2 system changes varying noise and system fragmentation using a representative C2 model. The goal is to extract fundamental understanding of Air Power C2 operating in an information age environment establishing a baseline and using a repeatable method. If the approach is successful, it may offer new insights into the detection and analysis required for the understanding many of complex C2 systems.

The AOC is not the only command node under human control that relies on an artificial representation of reality to make decisions and provide life-changing outputs. Using Conant's Model as a tool for describing human information processing has accomplished IT work in conjunction with NPPs (Kim, Soong, & Poong 2003). The following proposed model based on Kim, Soong, and Poong's 2003 work is used as a reference point.

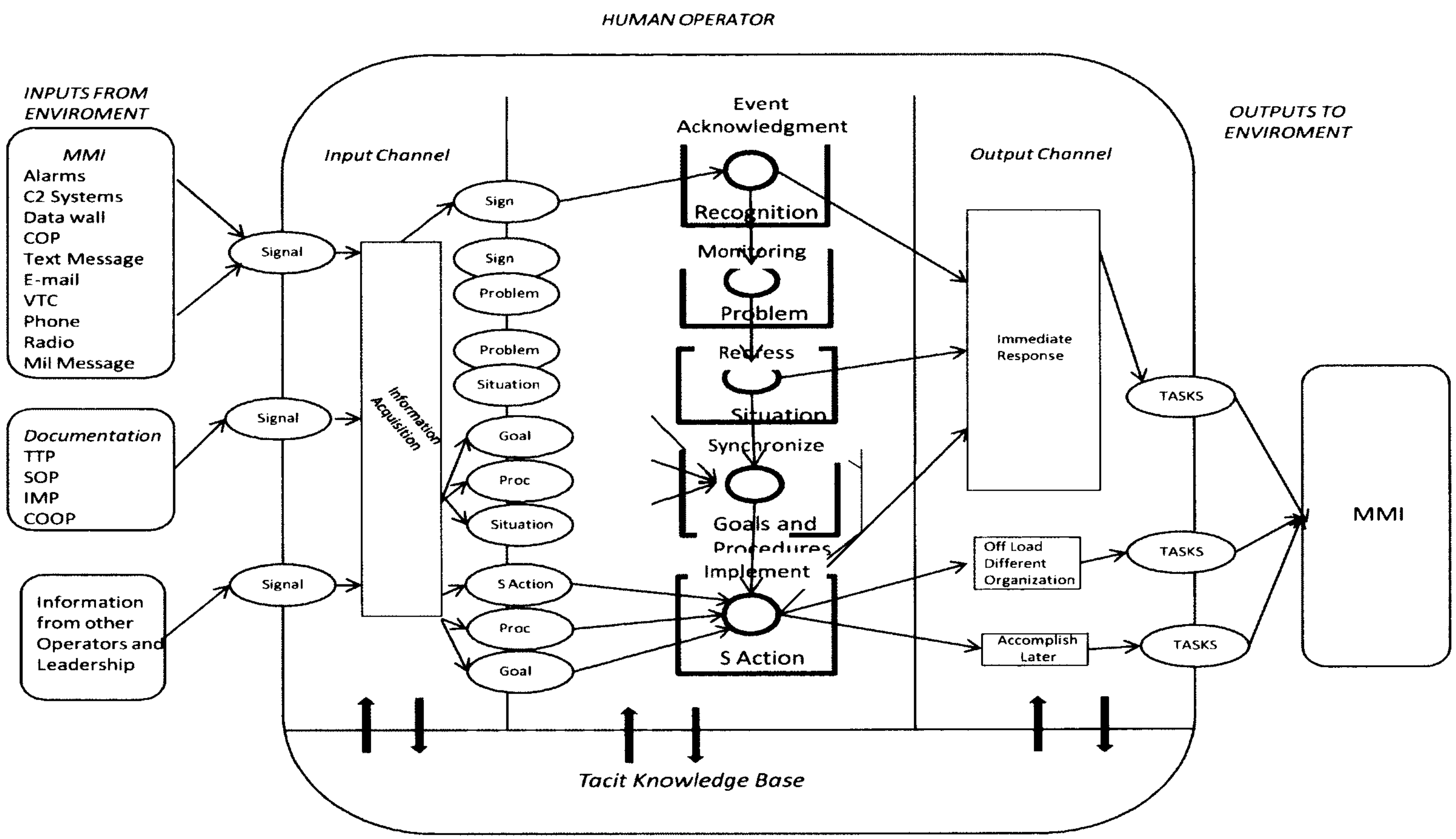



*Figure 4.* Modification of Kim, Soong, & Poong (2003)

Using cross-disciplinary tools of social networking and information flow to evaluate the AOC provides a proven repeatable quantitative measure.

Air Power Command and Control (C2) have unique characteristics. Air Power actions execute extremely quickly, and any coordination required to meet a new need (change in an ATO) has to happen well before the planned event occurs. Subsequently, the larger the change implemented, in turn, requires more coordination. There are general rules for the time required for planning an event, but they are coarse grain at best. There has been very little research using a repeatable method design specifically to understand core operational Air Power C2 issues. Successful heuristics exist in the crucible of combat, but it is best not to rely solely only on this method as the risk to mission accomplishment or loss of life can be extreme. Therefore, a human validated C2 model will function as the research milieu.

## 1.5 ASSUMPTIONS

Researching whether a model should be created, or if an appropriate C2 model was available, took several months. The Experimental Laboratory for Investigation Collaboration, Information-sharing and Trust (ELICIT) is a tool for modeling the behaviors of individuals in various organizational networks. Sponsored by a project within the Office of the Assistant Secretary of Defense (OASD) Networks and Information Integration (NII), ELICIT has an online multi-user software platform for conducting experiments and demonstrations in information-sharing and trust. Developers have reworked and refined ELICIT over a period of eight years. Direct development investment by the Command and Control Research Project (CCRP) has been greater than

$2 million. Researchers have provided significant additional resources (including human participants) directly. An international group of researchers has vetted and refined ELICIT. The software agents were developed and tuned based on data and experience with live participants. It is rare to have a research platform that supports both human and agent participants. The ELICIT software platform allows researchers and instructors to precisely model specific Command and Control (C2) processes, as well as edge organization processes and to fully instrument all interactions. The original project objective was to enable a series of online experiments to compare the relative efficiency and effectiveness of various organization types, traditional C2 vs. self-organizing, peer-based edge (E) organizational forms, in performing tasks that require decision-making and collaboration. ELICIT supports configurable task scenarios. The original baseline experiment task is to identify the 'who, what, where, and when' of an adversary attack based on information factoids that become known to individuals in a team or group of teams. The independent variable for the baseline experiment is whether a team is organized using traditional C2 vs. Edge organization principles. The software agent-based version of ELICIT (abELICIT) uses software agents whose behavior is defined by over 50 variables, which can be configured to model various social and cognitive behaviors, and operations and performance delays.

To date, both military and civilian institutions have run ELICIT with both human and software agent participants internationally. The agent behavior was modeled upon and validated against the actual behavior of human participants in ELICIT exercises. For this work, developers enhanced the existing tool to meet an emerging need. The original ELICIT tasks are intelligence scenarios. The ELICIT model was extended to handle a more complex operational scenario. ELICIT is modified to model the operational task of an Air Operations Center (AOC) issuing an Air Tasking Order (ATO) Change Order. The assumption is that the modified agent-based tool maintained its validation as compared to a human-based tool. Additional research could validate this assumption.

## 1.6 LIMITATIONS OF THE STUDY

Limitations of a study are the factors the researcher cannot control. Three factors limit this case study: (1) the core design of ELICIT; (2) the associated data collection tool; and (3) the data analysis tools. The baseline ELICIT task (Ruddy, 2007) is an intelligence task. Periodically during an experiment, ELICIT distributes *factoids* (i.e., information elements that are pieces of the scenario) to the participants. Participants can choose to disseminate or not disseminate factoids to others by 'sharing' (symmetric data movement) information directly with a particular participant or by 'posting' (asymmetric data movement) a factoid to a particular information system. However, only by communicating information can participants achieve sufficient levels of awareness to complete the task.

The four original baseline factoid sets each contain 68 factoids (four for each of the 17 participants). These factoids contain only true information. There is no incorrect or conflicting information.

Each baseline factoid set consists of 17 Key or Expertise, 17 Supportive, and 34 Noise factoids. Thus, the ratio of relevant information to noise is 50%. In the baseline factoid set, ELICIT distributes the factoids in three waves. Thus it is not until after that third wave that all the information is available to the participant group to fully identify the 'who, what, where and when' of the adversary attack. The factoids are evenly distributed so that by the end of the third distribution, each participant has received one Key or Expertise factoid, one supportive factoid, and two noise factoids. For purposes of the original experiment design, I took care to treat each participant equally. The factoid scenarios are anonymized to reduce distractions based on previous experiences.

I mapped the access matrix of each group to each information system website and instantiated them in an ELICIT organization configuration file (See Appendix C). Since some of the systems are 'read-only' with respect to some of the groups, I worked to enhanced the ELICIT organization file structure to support read-only access. I also configured this organization file to reflect whether point-to-point sharing was possible between the groups. I created variations on this structure to determine the efficiency and effectiveness of various intergroup process flows and procedures.

In addition to creating a new organization file, I also worked with ELICIT to create a new task scenario. I created a total of 51 Key and Expertise factoids, and mapped their order of precedence into seven sequential waves of information flow. In addition, I also created and mapped supportive and noise factoids. The operations factoid set is listed in Appendix C.

The 'what' data made available to the researcher are predetermined by ELICIT. As with any modeling and simulation base research, it is assumed the model is correctly coded and output data are what the researcher desires. ELICIT has developed an analysis tool to help the researcher sort through all resulting data. Both available analysis tools lack complete documentation, and it assumes all columns, rows, buttons, pull-downs and other functions listed correspond to a common/obvious definition of term supplied by creator of the applications.

## 1.7 DELIMITATIONS OF THE STUDY

Delimitations are factors of a study the researcher can control. The nature of this air power model based C2 case study may limit its generalizability. The following four delimitations bind this study:

1) This study will consist of only one model, the number of agents will be static, their interactions will be scripted, and the outcome decision is known as it is provided. Information derived from the study may not be capable of direct extrapolation to an actual AOC.
2) The rational human actor does not exist in the real world, and how actual combat decisions are made is well beyond the scope of this dissertation. Therefore, I made a limiting assumption to assume shared understanding (a measurable quantity) was equivalent to a decision.
3) The fundamental approach I took in this C2 effort is to map organizations interacting with the AOC to ELICIT participants and to model the key information flows between these groups as text base word strings. Required changes are categorized into configuration changes and coding changes. Only 28 groups are identified as related to the AOC Air Tasking Order change operation. In addition, I identified owners of only ten shared information points (webpages) (asymmetric data holding sites).

   Next, I configured 28 ELICIT software agents to represent each of the 28 groups' collective behaviors with respect to information flows with the other groups. For example, when a decision is made that a target should not be hit, the target is added to the no hit target list system. As is typically done with ELICIT agents, their actions were configured with a series of task process delays so that the time the agent takes to perform a task is mapped to human time rather than computer time. In configuring the agents, I found a few areas where modifications needed to be made to support posting of information to website names that were other than the traditional who, what, where and when names.

4) I derived relationships and organization structures from the best available information, so all limitations resulting from execration errors are solely the responsibility of the author.

## 1.8 DEFINITION OF KEY TERMS

The AOC weapon system (WS) is the operational level warfighting command center for air, space, and cyberspace forces. Like any military command node, the AOC can be represented as a task model because positional functions are well understood. This organization allows creation of operation sequence diagrams for deeper analysis. The (AN/USQ-163) Falconer AOC is the senior element of the Theater Air Control System (TACS) and provides centralized command, planning, direction, control, and coordination of air, space and cyberspace operations. The five divisions of the AOC are made up of numerous smaller teams: plan, control, assess air, space, and cyberspace operations. If other services or nations provide air, space, or cyber forces to a joint or coalition operation or campaign, the overall commander will normally designate a Combined/Joint Force Air Component Commander (C/JFACC) to control such forces. The fundamental tenet of this system is centralized planning and control through the AOC with decentralized execution by subordinate forces.

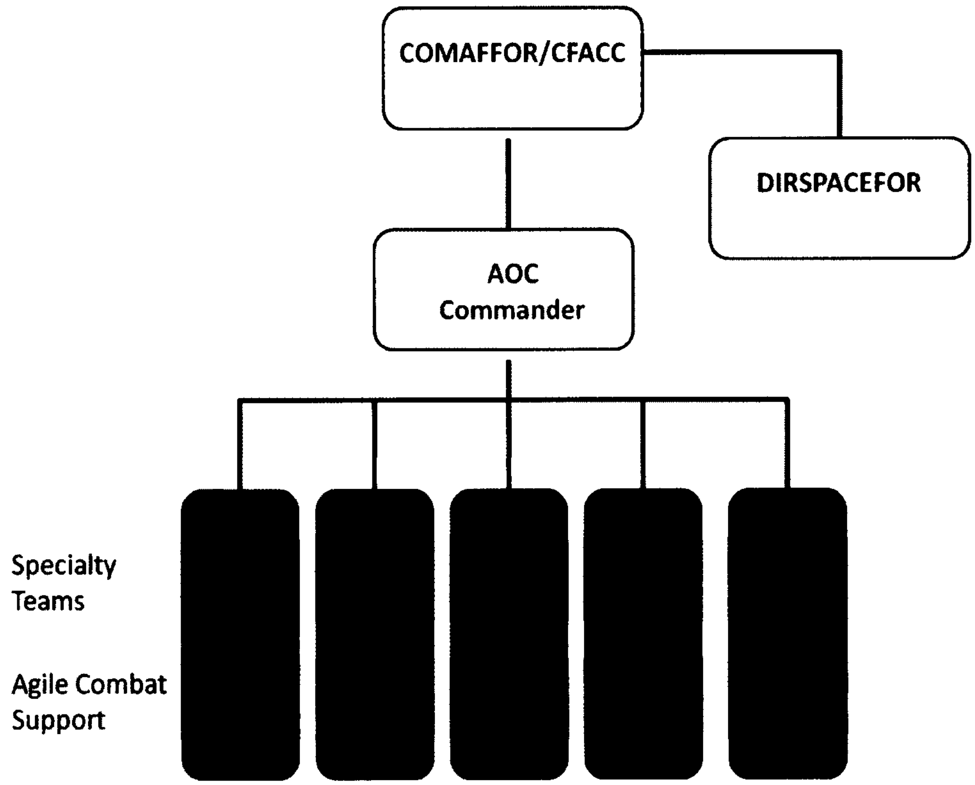



*Figure 5.* Notional JFACC Organization JAOC

The primary function of the divisions of the AOC is to produce and execute an Air Tasking Order (ATO) and associated documents like the Airspace Control Order (ACO). The Air Force has fielded five permanent Falconers worldwide to meet continuing air power challenges. In any operation involving air power, a single commander is designated the responsible member for all air power forces assigned and attached. In a theater-size military campaign, as many as 2,500 people inside the Combined/Joint AOC (C/JAOC) move massive amounts of information across multiple communication networks at various security levels. The CAOC provides the Commander the capability to direct the activities of assigned, supporting, or attached forces and monitor the actions of both enemy and friendly forces; the core processes remain the same. Figure 3 depicts a typical AOC, presented for reference only.

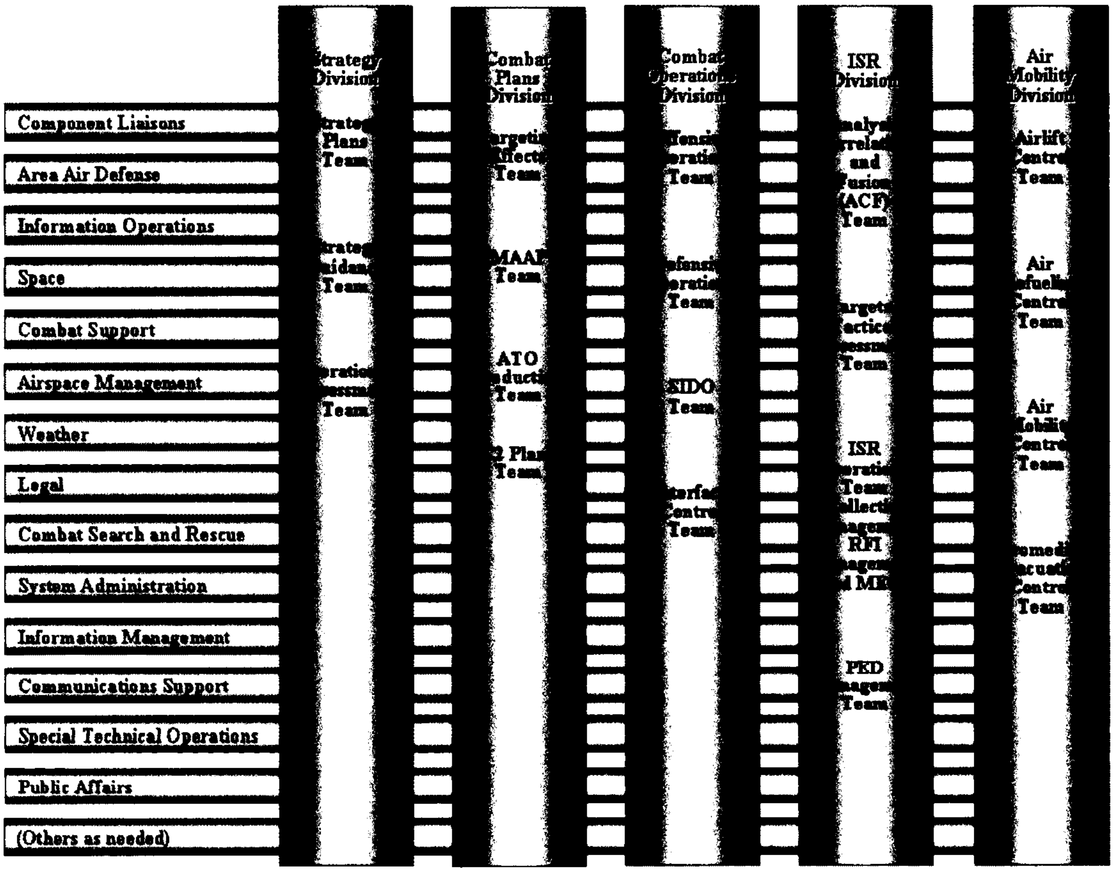



*Figure 6.* Generic AOC Organization

This dissertation evaluates only the Combat Operations Division (COD). The COD, Figure 9, executes the current ATO (e.g., the 24 hours encompassing the effective period). It is divided into four teams: Offensive Operations, Defensive Operations, Interface Control, and Senior Intelligence Duty Officer (SIDO). Time Sensitive Targeting (TST) and Combat Search and Rescue (CSAR) are two key processes that require immediate attention on the COD floor. Various specialty/support personnel are also embedded in the COD.

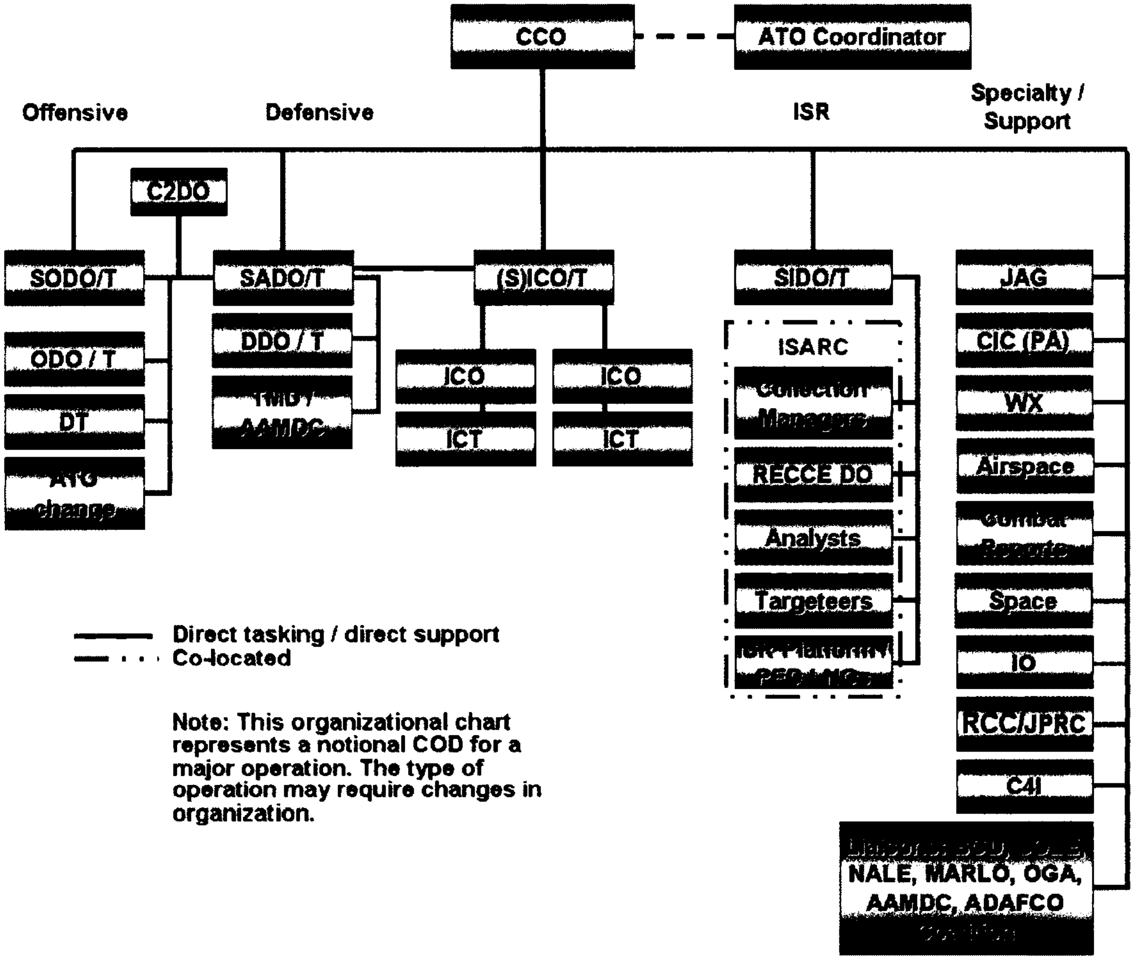



*Figure 7.* Notional COD

## 1.9 CHAPTER SUMMARY

When discussions associated with C2 became cantankerous and non-productive, one of my past supervisors would always ask, 'What is a pound of C2 worth?' Contingency theory states that there is no best way to organize; not all ways to organize are equally effective. The theory states qualitative rules observed through research on how companies organize in specific contexts, and how organizations with different structures perform in those contexts. For example, empirical research found companies engaged in routine predictable work perform better if they are more centralized and tightly controlled, whereas companies whose tasks have a higher level of uncertainty need to be decentralized and loosely controlled. In 1973, Jay Galbraith introduced an information processing view of organizations. The model abstracts work as simply as the quantity of information to be processed, and argues that the greater the uncertainty of the task, the greater the amount of information must be processed to complete it. Galbraith defines uncertainty as "the difference between the amount of information required to perform the task and the amount of information already possessed by the organization" (1973).

Researching C2 must be more about seeking a holistic synthesis of contemplation rather than a comprehensive analysis of mankind's follies and triumphs. By seeking to understand the potential benefit of cross correlating two major themes of thought (Social Networking and Information Theory), one may place a framework on a single command node within a single physical domain. The resulting investigating has allowed an extraction of truths. Only through deep inquiry can one strip away mythology and superstition in hope of establishing truths that withstand the test of time. One goal of this dissertation is to create a repeatable solution that extends the field of knowledge of Operational Air Power and C2.

Figure 8, below, summarizes the framework guiding this study:

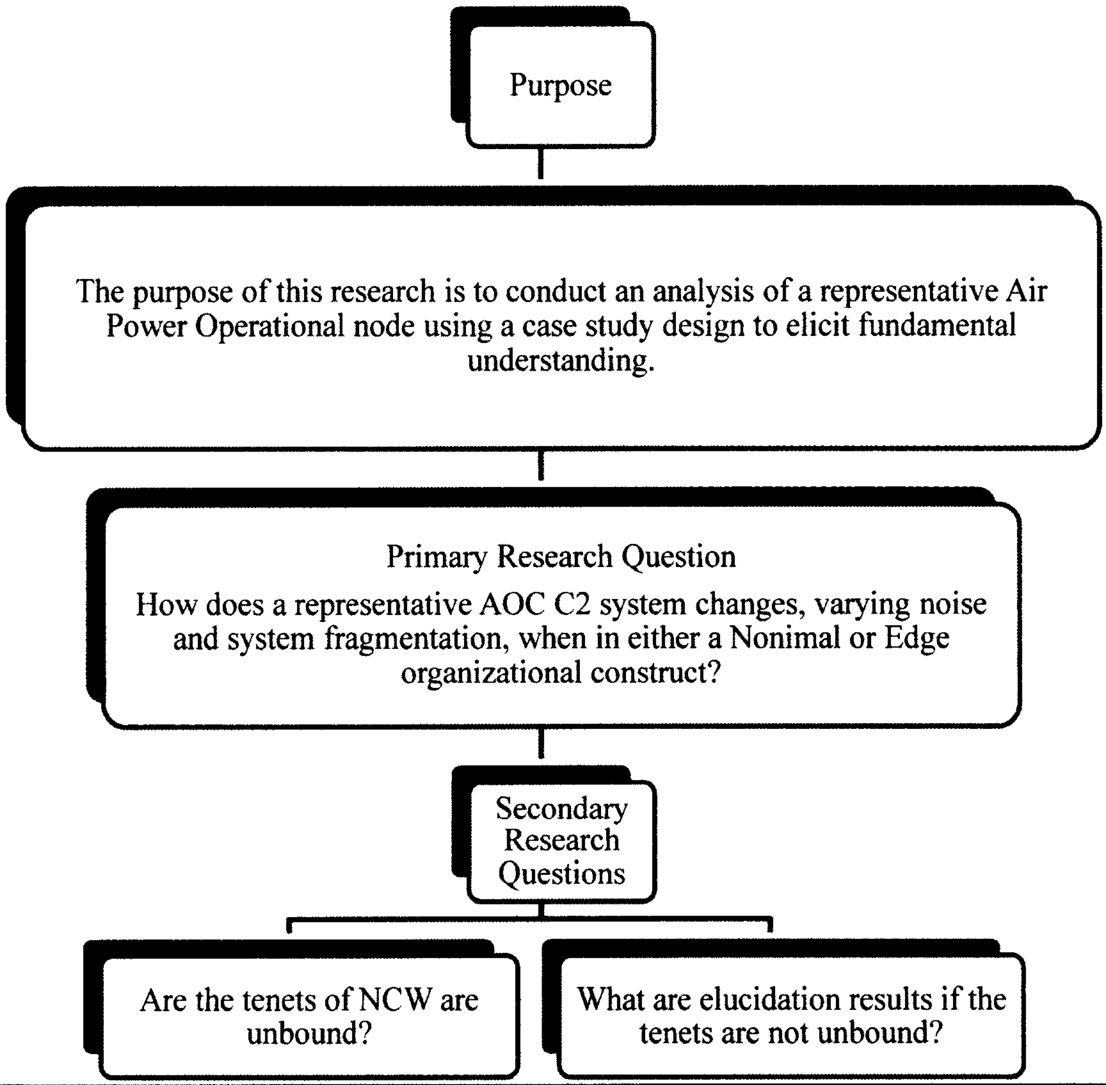



*Figure 8.* Guiding Framework

For readability a consolidate table view of this research exploration is proved and expounded upon in Table 8.

*Table 1.* The overarching goal is to link questions to research objectives

| Research Question | Linked Research Objective |
|---|---|
| How does a representative AOC C2 system changes, varying noise and system fragmentation, when in a Nominal or Edge organizational constructs? | Determine whether Critical Systems Thinking can be applied to military Command and Control |
| Are the tenets of NCW are unbound? | Recognize factors in NCW that are particularly influential |
| What elucidation results if the tenets are not unbound? | Identify and implement combinations of systems approaches that help Command and Control practitioners |

In Chapter 2, I will create a new lens to look at Operational Command and Control. Chapter 2 will appraise the literature. Chapter 3 will describe the methods and procedures applied for assembling and analyzing the data for this study.

# CHAPTER TWO - THEMATIC REVIEW OF THE LITERATURE

The study of Command and Control is such a broad subject that one could wander around it for years and never come out of the forest. When I started this journey, I had a basic understanding of my purpose and research questions. I knew I could work through creating a conceptual model and hoped I could generate output from a physical model. I did not know if I was going to find a physical model to use or if I would need to incur the cost both monetarily and of time required to build a model. Given my starting criteria, I searched for a process that would facilitate the journey. The process had to allow depth of inquiry, but more importantly, it had to allow a wide breadth of inquiry because I did not know what I would find in the literature or where it would lead me. According to Karl-Heinz Simon (2009) a critical systems endeavor has three intentions:

1. *Complementarism:* to reveal and critique the theoretical (ontological and epistemological) and methodological bases of systems approaches, and to reflect upon the problem situations in which approaches can properly be employed and to critique their actual use.

2. *Emancipation:* to develop systems thinking and practice beyond its present conservative limitations and, in particular, to formulate new methodologies to tackle problem situations where the operation of power prevents the proper use of the newer soft systems approaches,

3. *Critical reflection:* to reflect upon the relationships between different organizational and societal interests and the dominance of different systems theories and methodologies.

These three criteria aligned well with my purpose and research questions. I used CST as a bounding method to use my available time effectively. The following sections break down by Critical Awareness, Emancipation (human improvement), and Pluralism, and represent my voyage down a path less taken.

## 2.1 CRITICAL AWARENESS

Critical awareness is learning and thinking critically and deeply on both theoretical and practical matters on a subject. Command and Control (C2) has been around at least as long as militaries have been engaged in conflict; therefore reviewing the entire field of C2 would be a daunting task. Thusly, I will use Critical System Thinking (CST), as an enquiring process. Using CST allows one to consider a plethora of systems approaches when observing problems in order to improve the responses to situations that are dynamic and moving toward chaotic (Jackson, 2003). The purpose of this review is to achieve a readiness of action by defining slices of current literature in multiple fields. CST allows some articulation of the relevant myths and meanings of what is studied as well as defining the logic for achieving purposes, which can be expressed in the comparisons of what is teased out, challenged, and tested. The three theoretical commitments in CST are (1) critical awareness, (2) emancipation or improvement, and (3) pluralism (Jackson, 2000). CST is an appropriate research technique to understand fundamental C2 issues. A formal literature review would provide a valid and simplified method to start to accomplish that goal. In addition, C2 is quite a diverse term because it is broad enough to encompass many meanings and applies to many situations where other, more specific terms, e.g., communications, would convey a more accurate meaning. As Sutton (1986) points out, "Most of the articles are well worth reading, but one is soon convinced, to rephrase one old saw, that C2 is defined by the senior man present." In this case, it appears the terms Command and Control are often justified by the writer of the work instead of the senior man present.

As previously mentioned, Command and Control is viewed uniquely by each individual or organization depending on their perspective. Many believe that the modern term 'Command and Control' came about with the issuance of DoD Directive S-5100.30 in October 1962, entitled "Concept of Operations of the Worldwide Military Command and Control Systems (WWMCCS)." This directive set overall policies for the integration of the various Command and Control elements that were rapidly coming into being, stressing five essential system characteristics: survivability, flexibility, compatibility, standardization, and economy. The WWMCCS directive, though revised and declassified in December 1971 as DoDD 5100.30, remained in effect despite the fact that Lieutenant General Albert J. Edmonds, Director, Defense Information Systems Agency, officially deactivated the WWMCCS Inter-computer Network (WIN) on August 30, 1996 (Curts, 2008).

As is evident, this is a very system centered approach. It harkens back to a concept of cybernetics. The theory that implies if communication, control, and feedback were well managed, the synergy of human and computer systems would maximize the whole and, by default, render our forces superior to those of our enemies.

Another current definition in Western military thought is that defined in U. S. Joint Chiefs of Staff (JCS) Publication 1-02, Command and Control is "the exercise of authority and direction by a properly designated commander over assigned forces in the accomplishment of the mission" (p. 40). Command and Control, also called C2 (Department of Defense, 2001), is performed through an arrangement of personnel, equipment, communications, facilities and procedures employed by a commander in planning, directing, coordinating, and controlling forces and operations in the accomplishment of the mission.

Under Title 10, the warfighters of the US are the regional combatant commanders and not the JCS. The role of the JCS is to advise the President of the United States. It is easy to pick out words that quickly correlate back to that function.

The NATO definition is:

> Control: The exercise of *authority* and direction by a designated commander over assigned forces in the accomplishment of the force's mission. The functions of command and control are performed through an arrangement of personnel, equipment, communications, facilities and procedures which are employed by a commander in planning, directing, coordinating and controlling forces in the accomplishment of his mission. (NATO, 2008, p.2-C-14)

The NATO term *arrangement* could describe the political need to carry out any specified military mission defined by a group of countries, or even a single service specific definition as defined below United States Air Force:

> C2 is the exercise of authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of the mission. C2

> includes both the process by which the commander decides what action is to be taken and the systems that facilitate planning, execution, and monitoring of those actions. Specifically, C2 includes the battlespace management process of planning, directing, coordinating, and controlling forces and operations. (JP 1-02) (United States Air Force, 2011, p.47)

The role of any US service is to organize, train, and equip. One can glimpse those missions in the words selected. These differing perspectives define C2 as a complex system and synthesis of the seminal writers about complex systems (Beer, 1979, 1981, 1985; Flood & Carson, 1993; Jackson, 1991; Klir, 1991) validates that multiple, and possibly divergent views, will continue to appear from the various C2 stakeholder perspectives.

## 2.2 EMANCIPATION

In 1991, Flood and Jackson defined the philosophical support for CST as "emancipation," meaning "much broader dedication to human improvement" (p. 120). In 1995, the Command and Control Research Program (CCRP), within the Office of the Secretary of Defense, was created. During the 1970s, the Office of Naval Research and the Massachusetts Institute of Technology brought together interested researchers to exchange ideas on C2 and the impact of information revolution on the process. The first few conference meetings started out with only a few non-U.S. participants. Now more than 20 nations contribute.

Within the Office of the Assistant Secretary of Defense (NII), CCRP focuses upon improving both the state of the art and the state of the practice of Command and Control (C2), which enhances DoD's understanding of the national security implications of the Information Age. The CCRP pursues a broad program of research and analysis in Command and Control (C2) theory, doctrine, applications, systems, the implications of emerging technology, and C2 experimentation. It also develops new concepts for C2 in joint, combined, and coalition operations in the context of both traditional and non-traditional missions (Military Operations Other Than War (MOOTW)).

Key C2 concepts pioneered by CCRP include:

- Network Centric Warfare (NCW)/Network-Centric Operations (NCO)/ Network Enabled Capability (NEC)
- Power to the Edge
- Co-Evolution of Mission Capability Packages
- Domains: Physical, Informational, Cognitive, Social
- Effects Based Operations (EBO) and Effects Based Approach to Operations (EBAO)
- Campaigns of Experimentation (concept-based)
- C2 Approach Space
- C2 Maturity Models
- Model-Experiment-Model Paradigm
- Agility: Robust, Resilient, Responsive, Innovative, Flexible, and Adaptive
- C2 and Complexity
- Focus and Convergence

One of the seminal authors on current command and control is Dr. Richard E. Hayes (Alberts & Hayes, 1995, 2001, 2002, 2006; Hayes et al., 1993, 2001, 2006) (See Appendix B for the results of an interview with this seminal author).

### 2.2.1 Network Centric Warfare (NCW)

Network Centric Warfare is the best term developed to date to describe the way we will organize and fight in the Information Age. The Chief of Naval Operations, Admiral Jay Johnson, has called it "a fundamental shift from platform-centric warfare." (Johnson, 1998) NCW is defined as 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 knowledgeable entities in the battlespace. (Alberts, 1999).

### 2.2.2 Edge Power

The term "edge" derives from the recent book entitled *Power to the Edge* (Alberts & Hayes, 2003), which depicts new ways of organizing military forces and of enabling more powerful warfare by leveraging shared awareness and dynamic knowledge. The central premise is that power (i.e., the capability to accomplish intended actions) needs to flow from the "centers" of military organizations to their "edges." Using this metaphor, center refers principally to headquarters (e.g., where decision-makers request information from the field), and edge refers principally to front lines (e.g., where combatants—at the pointy end of the metaphorical spear—fight wars). The concept clearly involves more than simply realigning organization charts and reallocating decision rights. People at the edges of organizations must be aware of command intent, know how to accomplish tasks, activities, and processes, and be able to self-organize and self-synchronize to achieve the desired effects (Center for Edge Power, 2006).

### 2.2.3 Effects Based Operations (EBO)

Effects Based Operations (EBO) is an approach to planning, executing, and assessing military operations with an explicit focus on effects as opposed to targets or even objectives. Many people may ask: 'Isn't this the way we have always fought wars? Didn't we always focus on the effects we want to achieve?' The answer is yes. Commanders certainly always consider effects when planning and fighting wars. What are currently lacking but are in development are the automated tools to build and assess plans that link objectives to effects (including direct, indirect, physical, and behavioral effects, and the mechanisms through which effects are achieved), and then to link the effects and mechanisms to specific actions which need to be taken.

As stated, EBO is not a funded Program of Record (PoR) led by an office in the Pentagon; it is a mindset, a way of thinking in as much as it is a new methodology. EBO supports all mission types from Humanitarian Relief Operations all the way to Major Theater War. EBO could utilize lethal and non-lethal force such as information warfare.

EBO offers and requires an approach to modeling the enemy as a system, or, more specifically, a System-of-Systems (SoS). Enemy Center of Gravity (COG) or National Elements of Value (NEV) modeling can achieve this. We use the Warden COG analysis model and the Barlow NEV model to do this. What is important for EBO is to address not only COG analysis but also cross-cog analysis. For example, what effects does one COG such as infrastructure have on another COG, such as system essentials or leadership? EBO offers economy of force by specifying both dependencies and interactions between various target systems/COGs and mechanisms (McCrabb, 2001).

### 2.2.4 Disruptive Innovation and Experimentation

The book *Information Age Transformation: Getting to a 21st Century Military* (Alberts, 1996) acknowledges the fundamental obstacle to C2 progress: "Military organizations are, by their very nature, resistant to change" (p. 1). This is due in no small part to the fact that the cost of error is exceedingly high. When properly conceived and executed, campaigns of experimentation strike the proper balance between innovation and risk. As a result, organizations are able to embrace new concepts, organizational forms, approaches to Command and Control processes, and technologies. In other words, they are able to accomplish disruptive (transformational) change with an acceptable level of risk. Given the nature of military institutions, achieving the proper balance is not likely to occur without developing a broad-based understanding of, and a significantly improved ability to conduct, campaigns of experimentation (Alberts & Hayes, 2005).

### 2.2.5 C2 Maturity Model

NATO Network-Enabled Capability (NEC) has developed a Command and Control (C2) Maturity Model (N2C2M2), which is designed to provide guidance for the assessment of C2 approaches and capabilities under the conditions of Network Centric Warfare (NCW). N2C2M2 supports military organizations to determine where they are and where they want to go regarding C2 capabilities relative to those prescribed by the NCW vision (Alberts & Hayes, 2007). It identifies important milestones that nations must reach on the road to higher C2 maturity when seeking to contribute to NATO NEC by developing requisite C2 approaches and capabilities. It provides a framework that can assess the C2 capabilities of individual nations and collections of nations and other coalition partners. There are five steps in the maturity model:

1) Conflicted C2: In this, only existing C2 is exercised by the individual contributors over their own forces or sub-elements.
2) De-conflicted C2: In order for entities to avoid negative cross impacts of their intents, plans, or actions they need to be able to recognize potential conflicts and attempt to resolve them by partitioning the problem space as a function of, for example, geography, function, and/or time. This involves limited information sharing and limited interactions.
3) Coordinated C2: In this, overall C2 effectiveness increases by seeking mutual support for intent, developing relationships and links between and among entities' plans, and actions to reinforce or enhance effects with some initial pooling of non-organic resources.
4) Collaborative C2: In this, significant synergies are developed by negotiating and establishing shared intent and a single shared plan, establishing or reconfiguring roles, coupling actions, rich sharing of non-organic resources, and some pooling of organic resources.
5) Agile C2: This is built on Collaborative C2, and is distinguished by the entities' capability to self-synchronize, as well as the ability to recognize which approach to C2 is appropriate for the current situation, and to adopt that approach in a dynamic manner (Huber, 2008).

## 2.3 PLURALISM (INFORMATION FLOW)

Before the age of computers, we maintained information on paper. That paper became the object of a transformational workflow. In an Informational Technology (IT) environment, transformational workflow transpires between loosely coupled information systems and it is sometimes difficult to determine how humans transform input information into output information. A good example of the challenge in understanding how loosely coupled IT systems and humans interoperate is the Common Operational Picture (COP). Examination of a complete theater COP architecture diagram is similar to looking at a picture of the results of a 500 lb. bomb hitting a spaghetti factory; many little straight lines lying all over the place. Information is collected by a plethora of different equipment by organizations that are moving, sometimes on the ground or water or often airborne, or rotating into or out of theater. The raw data are fussed and correlated, transmitted across various non-harmonious physical layers using a surfeit of differing ports and protocols. The latent results are sometimes incomplete and always hard to validate as a total accurate representation of reality. The ensuing information flow pipes into the AOC. The result is that the actual COP is not the technical image displayed on a wall for all see, but rather a communal concept that each individual perceives about external ongoing reality.

The origins of Information Theory (IT) lie in C.E. Shannon's "A Mathematical Theory of Communication," published in 1948. Shannon (1948) proposed entropy as a measure of information, choice, and uncertainty. Entropy figures into such diverse communities as biology, decision theory, and thermodynamics. Bell Telephone Laboratories (in which Shannon worked) and Massachusetts Institute of Technology (MIT) expanded on Shannon's theory. Shannon never used the phrase *Information Theory* in a paper, but his emphasis on the term *information* helped coin the phase. The phrase implies that one could understand, study, and reduce to a math formula something as vague as *information*. Written for the communication field, Shannon's concepts developed in the late nineteen-forties soon slipped into the popular press. The initial enthusiasm developed into seminars, leading to classes producing graduate students that became the field's first practitioners. MIT's first field workers have cross-pollinated disciplines as diverse as Computer Science, Electrical Engineering, and Mathematics. For all fields, including C2, Shannon and his followers mathematically proved there are ways of encoding information that would allow flow up to a limit without any errors. The bad news is that after one reaches that limit, no matter how much money one spends on error correction equipment and/or process, one will lose some information.

Shannon's theory demonstrates how information relates to uncertainty, which can be given as a function. The amount of information, bits, is equal to the base 2 logarithm of the inverse of the probability:

$$H_i = \text{Log}_2 1/P_i$$

where $H_i$ is the amount of information and $P_i$ is the probability of occurrence of *i.* Using a formal mathematical construct for information, we can remove the human subject constraint concerning any 'value' of one generic informational blob (text-string) as compared to another.

Shannon's research provides the foundational work in understanding information flow. To dive into the depths of inquiry about C2 information flow, one must understand other seminal authors' works, of which there are at least three. I liken Shannon's Information Flow concept to the structure of an arch, in which three building blocks are used to create the final product: cornerstone (Conant, 1976), arch stone (Ashby, 1956), and key stone (Beer, 1979). The cornerstone is the first to be set; the arch is a truncated wedge that forms part of the arch ring; and the key is a central wedge-shaped stone that locks the parts together.

The corner stone of this work is Conant's (1976) law of partitioning of information rates, which addresses the allocation of total information processing ability to different tasks. Conant divides information in at least three categories. The first category is blocking of information, i.e., effort expended on information of no 'value' that may even damage the system, and which should not influence overall system activities. The second category is processing of information that should influence the system's behavior as it directly influences system output. The third category Conant posits is coordination. When a task is too large to handle by a single part of the system, it must be broken into manageable parts. Fracturing information flow creates the need for coordination. Determining the correct balance between work distribution and coordination is the lynchpin of efficient information transformation in which parties in the processing chain decide what they should do and what others inside and outside the AOC or any C2 should do.

Continuing the metaphor of how other writers' works need to blend into Shannon's (1948) core information flow concepts to bring vitality in C2 understanding, the arch stone of my work is Ashby's (1956) Law of Requisite Variety, in which a general law determines the capacity of a control node (regulator). In an information processing system like the AOC, the requirement on the regulator is information processing capacity as a communication channel, as shown by Casti (1985).

The key stone that holds the entire C2 Information Flow concepts together is Beer's (1979) proposition that complex systems be managed by regulation in which the different parts control their local milieu. Local control method of management should be considered as the system reaches a Pareto-optimum through the 'interactions' played by all the different constantly changing sub-organizations. Beer's (1979) concept fits nicely into AOC systems, where work is distributed among five core divisions and any number of cross-hatched specialty teams and no single person has control over the entire system.

## 2.4 THE MEANING OF INFORMATION

The term *information*, in its current usage, has no universally recognized definition. Shapiro and Varian (1999) state that "essentially anything that can be digitized - encoded as a stream of bits - is information" (p. 3). Shapiro and Varian's characterization fails to capture the aspect of information associated with transmission from sender to receiver. Conversely, Shannon's definition does not include the transition of meaning. Taken to the infinite, Shannon's concept attributes a larger amount of information to a random sequence of letters than it does to a sequence of letters that compose a word. Weaver, in *The Mathematical Theory of Communication*, (Shannon & Weaver, 1949) reinforces that Shannon's *information* "must not be confused with meaning" (p.117). Machines can pass a great amount of information; humans as communication channels are extremely limited.

Communication channel capacity is very low when humans converse. Our bandwidth is less than 100 bits/second (Nørretranders, 1991). Nørretranders' concept posits that a sender starts with an idea that he wants to communicate. He consolidates this idea in language through models and metaphors. If the receiver shares the same models and metaphors, he or she will comprehend the information and its underlying associations by mentally expanding it. A good example of the success or failure of the mental model-sharing concept would be when two people use a shared second language to try to communicate abstract concepts. In *Diagnosing the System for Organizations*, Beer (1985) stresses that a message may distort at any location within the system. He points out that the transduction; i.e., when the message is translated from the type of message sent in the communication channel to the kind of message understood by the receiving end, is the most vulnerable spot. Even in a paper-based system, its recipient may not correctly understand a message, though both parties are fluent in the same language. In an IT world, where parties may or may not share a common presentation layer, user application incongruities in understanding can quickly arise. The interpretation of the meaning or underlying value of the information has a direct effect on control/regulator functions. The value of information is limited if the recipient cannot interpret the totality of what the sender is attempting to communicate. For this research, information is defined as factoids (human readable word strings).

## 2.5 DEFINING SYSTEM FRAGMENTATION

System Fragmentation is the "ugly baby" in the room that is C2; very few want to think intelligently about it. System theory points to the fact that all systems, as they change over time, will move in the direction of fragmentation and differentiation (Kast & Rosenzeig, 1985). When differentiation is one's strategy for success, fragmentation will happen. In natural systems, we see this process happening in bees or ants or in the evolution of an entire species. In man-designed systems, the process is replicated; one need only observe the many different one-off, spinoffs, rip-offs and other-off's of any truly uniquely beneficial design, product, service or concept. System theory also tells us that all systems will experience a counterbalancing imperative to seek integration and convergence to cover the common principles that underline their functioning. (Katz & Kahn, 1978). System fragmentation/specialization can have benefits, like lower nodal cost, but at the same time, it brings a range of complicating problems. System fragmentation is the "ugly baby" in C2, not because it going to happen, but because no one knows how best to management it in a knowledge age. Here are two classic military examples: All militaries can divide into organizational blocks, and when the blocks fail to function as expected, the organization can reorganize, rearm, and reequip as needed. In the Information Age, with massive amounts of static infrastructure required to move data, will any new organizational structure be more than deck chairs on the Titanic? Industrial Age systems were divided along the specialty functions; the army got the tanks and the navy got the ships. Should that same philosophy be used in knowledge intensive management organization? In the AOC, should each of the five divisions, or maybe even all of the specialty teams, have their own systems, or be supported by multiple systems? If a single large system, it should be remembered that in 1991 a single mistyped character in a single line of code knocked 12 million customers of AT&T offline.

The AOC systems are divided along two primary system fragmentation lines. The first fragmentation line is formed by the Management Information Systems (MIS) that at their underpinning rely on commercial standards, and are often defined as Commercial-of-the-Shelf (COTS). The other line of fragmentation is defined by C2 systems that are built on government/Mil-Standards and are often defined as Government-of-the Shelf (GOTS). An example of an MIS system would be e-mail and example of a Mil-STD system would be Link -16. Over time, many AOC C2 systems have acquired at their core COTS technology. An example would be Theater Battle

Management Core System (TBMCS). TBMCS is used to build the ATO (a military standard message), but has an Oracle database to store the data and sends the ATO to other units using Simple Mail Transfer Protocol (SMTP) (a COTS standard).

The AOC can be divided in many different ways to be observed, as can any complex system. One way to look at the AOC is to quarter the AOC by systems. The upper left quarter would be systems that provide Situational Awareness (mostly GOTS). The upper right would be systems that produce messages like the ATO and ACO (mostly GOTS). The lower left would be systems that provide/produce Intelligence (again mostly GOTS). The lower right would be made up of the explosion of COTS products from web-pages, to e-mail, to VTC, to digital phones, and the most newfangled toy.

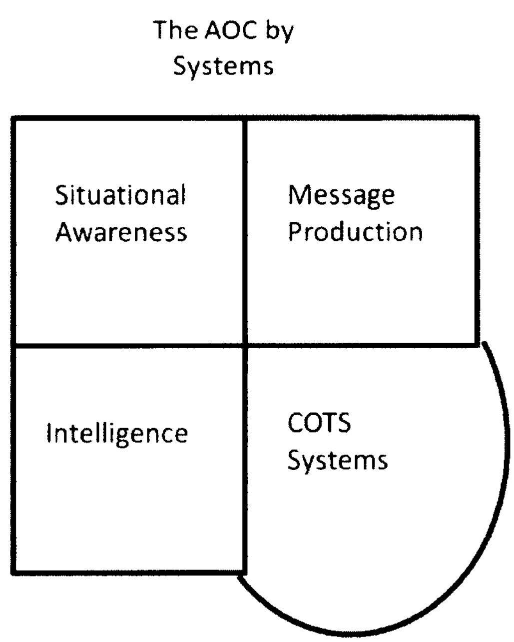



*Figure 9.* The AOC by Systems

In the Information Age, and based on history, the number and functions of COTS systems is likely to grow.

| | 1992 | 2012 |
|---|---|---|
| Broadcast | Broadcast & Cable TV, broadcast radio | Broadcast TV, cable TV, Broadcast radio, satellite radio, podcast, streaming video and audio (e.g. Huli, Netflix, iTunes, Amazon, YouTube, Pandora and hundred of other streaming services), cinema, music sharing (e-g. Spotify) |
| Print | Newspapers, magazines | Newspapers, magazines, iPad, Kindle, Nook and many other e-readers, RSS feeds, social bookmarks (e.g. Digg, Reddit) |
| Direct | Direct mail, telephone | Direct mail, telephone, e-mail, pURLS, SMS Test messaging, mobile apps (push notifications) |
| Outdoor | Billboards, transit posters | Billboards, transit posters, digital outdoor signs, projections on sides of buildings, outdoor installations |
| PR | Press releases, media events | Press releases, media events, blogger outreach |
| In-Store | Printed or handwritten POP signs | Printed or hand-written POP signs, digital POS signs, motion-activated coupon dispensers, touch-screen POS kiosks, mobile shopping apps, location-based/GPS-enable apps/devices |
| Digital Devices | Walkman CD and cassette Players | TiVo/DVRs, iPod/MP3 players, game consoles, portable gaming devices, laptops/PCs |
| Online | Didn't exist | Websites, mobile web, Smartphone and tablet apps/games, banner ads, rich media ads, video ads, websites takeovers, location-based technologies, 2D barcodes, NFC, streaming video and audio (e.g. Hulu, Netflix, iTunes, Amazon), personal online chat/IM, live public discussions, webinars |
| Social Media | Didn't exist | Facebook, Twitter, Linkedin, YouTube, Printerest, Instagram, Foursquare, and hundreds of other social networks, forums, discussion boards, over one million active blog/vlogs, video and audio podcasts, online gaming |
| Mobile | Didn't exist | Mobile phones, smartphones, tablets, e-readers |

*Figure 10.* Fragmentation of various Systems (Kuefler, 2012)

In the paper, "US Army Information Technology Management" by Casazza, Hendrix, Lederle, and Rouge (2012), the authors argue convincingly that the very structure of a US military organization inhibits adaption of new technologies:

> [T]he U.S. Army remains the most technologically sophisticated military force in the world, extraordinarily efficient and effective at its mission to defend and protect the peace and security of the United States, its national interests, and

> objectives. However, when attempting to integrate the rapid advancements made in information technology, it has invested considerable resources with little success. As argued in this paper, this is not the result of technological issues, but rather ones of the convergence of the technological and the social. The very organizational structure that has served the Army well in consistently delivering on its mission through frequent turnover, extreme circumstances, and immense size is also at direct odds with the type of organizational structure embodied by information technology. (p. 3)

Rigid rules, parallel hierarchies, systemic division of labor and authority, and elaborate processes do well for establishing and maintaining civilian control of a continent-spanning organization which may be called upon to fulfill dangerous missions in unknown circumstances, and in which new personnel may be rotated frequently. However, the benefit of IT as defined here, is to transform an organization, rewrite those rules, and make them constantly adaptive to new circumstances. System fragmentation and the corresponding knowledge fragmentation will take place; I believe that the fragmentation can be modeled and measured to determine how that fragmentation affects the overall man-machine system of the AOC. For this dissertation, I modeled system fragmentation by increasing the number of webpages per site and decreasing the trust in the information available on each individual webpage.

## 2.5 HUMAN LIMITATIONS

Humans are self-organizing, problem solving creatures. If one looks closely at operators as a group, great variability is evident in how each operator performs his perceived task. Some reach the leadership asymptotic performance approaching perfection, but many others do not. Aristotle posited four levels of abstraction that operators use to interpret and explain their reality. Aristotle's four levels of generalization about function and cause are: formal, material, efficient, and final. At the formal level, a light switch (function) will turn a light bulb on if one moved the switch to the 'up' position (cause). At the material level, the light came on (function) because a pair of 'hot' electrical contacts moved to close a circuit (cause). At the efficient level, the incandescent filament illuminated (function) due to current flowing to the bulb (cause). At the final level, someone turned the light on (function) because it was getting dark (cause). Human short-term working memory ranges from approximately 7 + or – 2 objects at any given time. The higher the abstraction an operator uses, the lower the number of objects about which he must think. For example, it is easier to think about a car then it is to think about the parts in a drive train, or all the parts in an engine, or what is happening in each cylinder on each stroke. Moving up the abstraction level reduces workload and facilitates transmission of concepts to other individuals operating at a similar level. Accurate higher-level abstractions form in formal training or through experience as one-to-one and many-to-one mappings are made. One does not need to understand what is going on under the hood when a car makes a 'funny' sound. The driver and the mechanic do not possess a one-to-one mapping of function to cause, and trying to communicate to the mechanic that lower level detail soon becomes nearly impossible, meaning the mechanic and the non-knowledgeable driver never achieve successful communication and each must ineffectually move forward. The mechanic's job would be easier if the driver used words like the 'the mechanical lifters are knocking under a heavy load.' The driver would not be so shocked at the bill if the mechanic had not had to explore three or four possible problems before stumbling into the actual issue. Just because two people share a common root language does not mean each participant achieves an exchange of ideas. Higher levels of abstraction are homomorphs of lower levels. In other words, a high level generalization preserves the causal relationship, but with loss of detail. For this research, I will extract information only to the highest level. Differing level of abstraction of concepts point to why a strict quantitative analysis approach does not provide complete understanding on many C2 issues.

## 2.6 THE SYSTEM

The AOC is not the only command node in the human condition that relies on an artificial representation of reality to make decisions and provide life-altering outputs. The operations center of a nuclear power plant (NPP) or any other directing organizational node takes from reality a subset of facts and begins the decision making process based on them. The challenge in the cognitive organizational design process is to recognize and anticipate 'facts' that are appropriate, and, if they are captured, whether they create in the mind of the operator an accurate representation of reality.

Current AOC organizational realities contain (1) a high degree of technological complexity to manage massive amounts of data, (2) non-linear, knowledge-intensive work, (3) changing battlespace influencing work system effectiveness, and (4) turbulent mission requirements. This predicament is a result of the AOC attempt to monitor and control everything within a complex system scattered over thousands to hundreds of thousands of square miles. Therefore, Air Power reality has many open-system characteristics. To attempt to capture some open-system characteristics of the AOC, organization elements outside the AOC will make up a sufficient number of ELICIT agents.

**2.6.1 Shannon's (1948) Concept**

As stated previously, any electronically stored, transmitted, or recorded data is neither information nor knowledge. Humans supply context to these mathematically defined and physically manipulated voltages. At the same time, the language of data/ knowledge/ information can convey an appropriate exchange of authenticity. Any military Corps or above organization, like an AOC, often use electronic data encapsulated in language to exchange understanding and meanings with other war-fighters and should organizationally be considered a knowledge management entity. Humans do not exchange information in *0's* and *1's*, but it is valid to use information flow theory to elucidate what happening inside the AOC.

I provide Shannon's (1948) general concept of a communication system in

(Schematic diagram of a general communication system) (Shannon & Weaver, 1949):

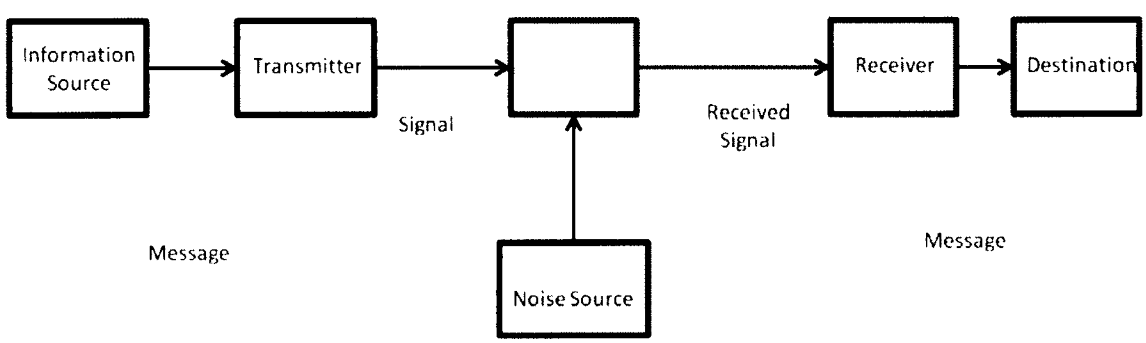



*Figure 11.* Shannon's (1948) General Concept of a Communication System

Shannon and Norbert Wiener's (an early MIT collaborator) measure for the amount of information in a message is the amount of uncertainty it removes. Hence, to determine the amount of information a recipient receives in a message, Shannon (1949) starts with all possible messages that could have arrived. Assume that the number of possible messages is W and let p =1/W. Further, let $p_i$ denote the probability that message $p_i$ is transmitted. Shannon defines the amount of information as information entropy, which is calculated as

$$I = -k\sum p_i \log p_i$$

with $k = 1$ and 2 as the base of the logarithm. The result is the quantity of information in bits in which one bit is defined as the choice between two alternatives. If the expected message is a character of the English alphabet, the other 25 characters represent the uncertainty removed. If all characters are equally probable $(p_i=1/26)$ and I convert to 2 as the base of the logarithm, I get

$$I = -\ 1/\ln 2 * \ln 1/26 = 4{,}7 \text{ bit}$$

as the amount of information in one character.

Shannon and Wiener's (1949) mathematical definitions differ in that Shannon multiplies the sum with minus one, whereas Wiener does not. However, as pointed out by Ashby (1948), when one is interested in the gain in information, the sign makes no difference. One must meet two requirements before measuring Shannon-information. First, there must be an uncertainty—the question must precede the answer. Second, the uncertainty must be measurable. A drawback of Shannon-information is that it bears no direct reference to meaning. However, applying the concept more loosely, one may read meaning in 'uncertainty removed.' One reason for using Shannon-information is that it fits nicely into the theory of sets and is applicable to the 'set-ness' of a system. Furthermore, it is suitable in discussing the role of information used for control. While Shannon (1948) developed the measure for studying communication systems, Wiener developed it to study control of systems. Shannon and Weaver (1949) define that it is appropriate to use the volume of factoids moving through the system at any time as a change measurement mechanism.

Sommerhoff (1950) specifies five variables that can represent the macro air power system:

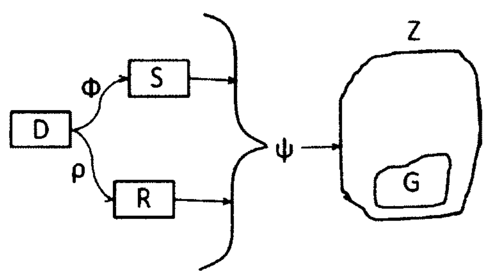



*Figure 12.* Modification of Sommerhoff's Five Variables (Summerhoff, 1950).

(1) where Z is all events that may occur—intended, untended, some good, some bad (Set Z in Ashby's (1967) reformulation in terms of set theory.);

(2) the set G, a sub-set of Z, consisting of 'good' events, those that one perceives will result in favorable outcomes;

(3) the set R of events in the *AOC* and the resulting outputs;

(4) the set S of events in the rest of the open system, which is reality (e.g., position of aircraft and amount of fuel in their tanks);

(5) the set D of primary disturbers (Sommerhoff's 'coenetic variable'); those that cause the events in the system S, tend to drive the outcomes out of G: (e.g. weather, higher headquarters, emergencies); and

(6) this formulation has withstood 60 years' scrutiny and covers a majority of cases.

It is also rigorous (Ashby, 1967) and each value (Figure 12) evokes the next:

$$\acute{\phi} : D \rightarrow S$$

$$\rho: D \rightarrow R$$

$$\psi : S \times R \rightarrow Z$$

then 'R' is a good regulator (for goal G, given D, etc., $\acute{\phi}$ and $\psi$)' is equivalent to

$$\rho \subset [\psi^{-1} (G)]\acute{\phi}.$$

to which I must add the obvious condition that

$$\rho\rho^{-1} \subset 1 \subset \rho^{-1} \rho$$

to ensure that ρ is an actual mapping, and not the empty set. In addition, there is no restriction to laniary.

The criterion of success of the AOC is not whether the outcome, after each interaction of S and R, is somewhere within G, but whether the outcomes, on some numerical scale, have a root-mean-square vectoring toward zero.

There are two basic methods by which the AOC can inject control inputs in attempting to influence reality (Z). One method is provision of error-control inputs or cause-control inputs. In terms of Operational Air Power, one could define Error-Control inputs as the number of bombers available to send based on their circular probability of error (CEP). CEP has decreased from that extent in World War I, and the number of bomb-laden aircraft sent to destroy any given target has proportionally decreased. The other method is cause-control input. Higher biological organisms have evolved to use more effectively information about the causes (at D) as the source and determiner of their actions. An Air Power example of cause-control is if a warfighter is assigned airborne Close Air Support (X-CAS) and there is no movement at the primary target, the warfighter can be rolled into a secondary target. Error-control is a less effective method of air power execution as the entropy of the outcome Z cannot be reduced to zero: its best success can only be partial. Sommerhoff's (1950) macro model provides the conceptual underpinning that although the Operational C2 model does not achieve error-control, it does use cause-control as a recognized throttling technique.

**2.6.2 Conant**

Conant (1976) used the information theory to analyze real world systems. Conant considers a system S as an ordered set of variables S = {Xl' X2.... ,X,J. Those variables in S that can be directly observed from its environment constitute output variables. The set of these output variables is denoted So = {Xl' X2 ,... ,Xk}, with 1`k`n. The remaining variables within S are internal variables, denoted as Sint. Hence, S = {Sinll So}. Let E (the environment) denote all relevant variables outside S.

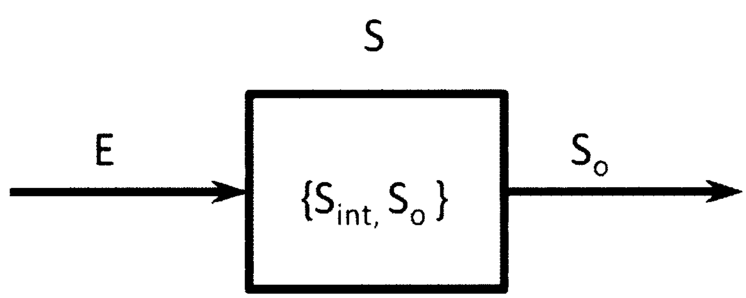



*Figure 13.* Visual depiction of Conant's Information Flow Concept

Conant (1976) employed the idea of using information theory to gain understanding of systems, although Brillouin (1962) had already applied a similar idea with respect to scientific reasoning. Conant used the theory to better understand real-world systems, although he admitted that "...there are obvious dangers in applying information theory, designed for use under severe mathematical constraints of stationarity and ergodicity, to real-world systems thus not constrained" (Conant, 1976, p. 63). However, the justification lies in the fact that instead of being content to say nothing about information, a far more preferable course is to try to use results from a formal theory by judicious interpretation and generalization (Conant, 1976).

In his book, *Alternate Realities: Mathematical Models of Nature and Man,* about mathematical model building, Casti (1989) comments on the lack of consideration of such basic questions in the following manner:

> As noted by Rosen (1986), in dealing with the idea of a natural system, we must necessarily touch on some basic philosophical questions of both an ontological and epistemological character. This is unavoidable in any case and must be addressed at the outset of a work as this, because our tacit assumptions in these areas determine the character of our science. It's true that many scientists find an explicit consideration of such matters irritating, just as many working mathematicians dislike discussions of the foundations of mathematics. Nevertheless, it is well to recall the remark of David Hawkins (1989), "Philosophy may be ignored but not escaped; and those who ignore most escape least." (p. 1-3)

Conant's model is regarded as a useful tool for describing human information processing, especially for the information flow of diagnosis tasks that are relatively static. Based on the information theory, the amount of information is simply equal to the base 2 logarithm of the inverse of the probability:

$$Hi = Log2\ 1/pi$$

where $H_i$ is the amount of information $p_i$ and is the probability of the occurrence of an event. The average information conveyed by a series of events with different probabilities is computed as

$$H = \sum_{i=1}^{n} p_i \ Log_2 1/p_i \tag{1}$$

where

$$\sum_{i=1}^{n} p_i = 1$$

and $p_i$ probability of occurrence of event $_i$.

Equation (1) is the same as the mathematical definition of entropy in statistical mechanics. Information relates to uncertainty. An important characteristic of (1) is that when events are not equally likely, H will always be less than its value when the same events are equally probable.

The amount by which two variables are related (i.e., they are not statistically independent) is measured by the transmission between them, $T(X_1: X_2)$, denoted as and defined through probabilities, or by:

$$T(X_1: X_2) = H(X_1) + H(X_2) - H(X_1{:}X_2) \tag{13}$$

$H(X_A, X_B)$ denotes the total information corresponding to the combined occurrence of A and B. The transmission is a measure of relatedness between variables, which accounts for its usefulness in system science. $T(X_A, X_B)$ falls in the interval

$$[0, \min,\{H(X_A), H(X_B)\}],$$

being 0 if and only if *A* and *B* are statistically independent and maximum if and only if one variable determines the other.

Conant (1076) considered a system $S = \{X_1, X_2, \ldots X_n\}$. Those variables in *S* that can be directly observed from its environment constitute output variables. The set of these output variables is denoted as $S_o = \{X_1, X_2, \ldots X_k\}$, with $k \leq l \leq n$. The remaining variables within *S* are internal variables, denoted as $S_{int}$. Hence, $S = \{S_{int}, S_o\}$. *E* denotes all relevant variables outside *S*, namely environmental variables. Next, Conant obtained an expression for the total information *F* (in bits) as a measure of the total processing activity within *S*.

$$F = \sum_{j=1}^{n} H(Xj) = F_t + F_b + F_c + F_n$$

The different constituents of *F* are defined as follows:

| | |
|---|---|
| Throughput Rate | $F_t = T(E{:}S_0)$ |
| Blockage Rate | $F_b = T_{so}(E{:}\ S_{int}) = T(E{:}\ S) - T(E{:}\ S_o)$ |
| Coordination Rate | $F_c = T(X_1, X_2, \ldots X_n) = \sum_{j=1}^{n} H(Xj) - H(X_1, X_2, \ldots X_n)$ |
| Noise Rate | $F_n = H_E(S) = H(E,S) - H(E)$ |

$H_A(B)$ denotes the amount of information in A, conditional on B; it is the amount of information in A when B is known.

The total information flow for a system is expressed as

$$F = \sum_{i=1}^{N} Fi$$

where *i*: a subsystem of a system *S*.

The total information flow in system *S* is represented by the sum of the total flow for the subsystems. The total flow *F* is also the sum of the entropy of the individual variables. It represents the total activity in *S* if inter-variable relationships are ignored. Conant also pointed out that one could view *F* as the total amount of 'computing' going on in *S*. Subsequently, the total activity can be expressed by the sum of four terms (or activities), that is, throughput, blockage, coordination, and noise. The throughput $F_t$ measures the input-output flow rate of *S*, or the number of bits per step passing through *S* as a communication channel. The blockage $F_b$ is the amount of information about the input *E* that is blocked within S and not allowed to affect the output.

*Table 2.* Constituents of Total Information F

| Formula | Result |
|---|---|
| $F_t = T\,(E : S_o)$ | Throughput Rate |
| $F_b = T_{so}\,(E : S_{int})$ $= T\,(E : S) - T\,(E : S_o)$ | Blockage Rate |
| $F_c = T\,(X_1 : X_2 : \ldots : X_n)$ $= \sum_{j-1}^{n} H(Xj) - H\,(X1,\ X2, \ldots, Xn)$ | Coordination Rate |
| $F_n = H_E\,(S)$ $= H\,(E, S) - H\,(E)$ | Noise Rate |

The relationship of mathematical formulas can better be understood from the following graphical depiction.

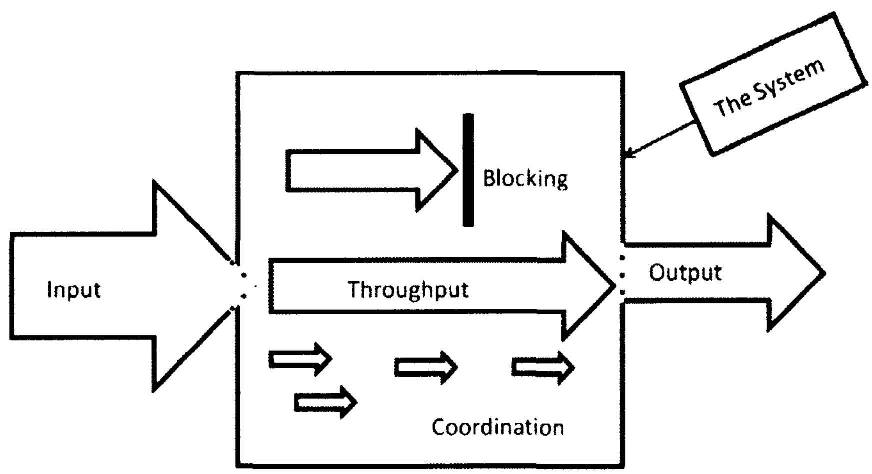



*Figure 14.* Conant's (1976) Model, Describing Blocking, Throughput and Coordination

The coordination $F_c$ represents a measure of the total relatedness between all the variables in S. The noise $F_n$ represents the amount of internally-generated information in the process. The dimension of these terms is bits.

- Ft is the throughput rate and is a measure of the relatedness between input and output, the term transmission engineers wish to optimize where S is a transmission channel.
- Fb is the blockage rate and represents the effort needed by S to block non-relevant information (e.g., if S is a system that from a sequence of natural numbers only presents the prime numbers at its output, then S internally blocks all the non-prime numbers).
- Fe is the coordination rate and represents the amount of information processing needed to obtain a coordinated action among the system variables (i.e., subsystems) of S.
- Fn is the noise rate and reflects the amount of information in S that is not reflected in (i.e., dependent on) the input to S; in case of the transmission channel this is the noise present at the channel.

Information also relates to uncertainty. The transmitter may send certain messages. Before the arrival of a message, the receiver will be uncertain as to which message they will receive. After arrival of the message, less uncertainty (possibly zero) is left. The difference between the two amounts corresponds to the information in the message. This information is expressed in bits. Let B denote the situation before the arrival of the message and let A denote the situation after arrival; then H(B,A) denotes the information in the message. In general H(A/B) denotes the amount of information in A, conditional on B; it is the amount of information in A when B is known.

T(A:B) is the transmission between A and B and is a measure of the relatedness of A and B. It is defined as:

$$T(A:B) = H(A) - H(A|B) = H(B) - H(B|A)$$

It is zero if A and B are independent and maximum if one determines the other. In the case of a noiseless transmission channel:

$$T(A:B) = H(A) = H(B)$$

A simple decomposition rule will be used. Let H(A,B) denote the total information corresponding to the combined occurrence of A and B. Then the following rule holds:

$$H(A,B) = H(A) + H(B|A) = H(B) + H(A|B)$$

This expression states that the information in the combination of A and B is the information in one of these plus the remaining information in the other when the first is known. With these basic notions, the different constituents of F can be defined as follows.

*Table 3.* Information Flow

| Formula | Result |
|---|---|
| $F_t = T\ (E : S_o)$ | Relatedness (transmission) between the environment and the output |
| $F_b = T\ (E : S_{int/\ So})$ | Transmission between the environment and the internal variables when the output is known |
| $Fc = T\ (X_1 : X_2 : \dots : X_n)$ | Transmission between the variables of S |
| $F_n = H\ (S/E)$ | Information in S when E is known |

Conant's (1976) work validates that data movement through an organization can be measured and quantified over time and against organizational structure.

**2.6.3 Ashby's (1956) Law**

In any system, the various entities and relationships that make up the structure may be in different conditions, and the state of the system is the totality of all these various conditions. A systems variety is the number of different states it can be in Ashby (1956); similarly, there is a variety in the system's input and output. Hence, one may interpret variety as a measure of one aspect of systemic complexity (Beer, 1985).

One of the arch stones in our analogous arch is Ashby's (1956) Law of Requisite Variety, which establishes a relationship between the capacity of a regulator and the controllability of a system.

Consider a system with a regulator *R*. Assume further that one wants the system to remain at a particular state. The system is under the influence of disturbances from its environment that threaten to drive the system away from its desired state. Ashby's (1956) Law of Requisite Variety gives a minimum requirement on the *R*'s capacity for the system to be controllable. According to Ashby's (1956) Law of Requisite Variety, for a system to be successfully controlled, the variety of the regulator must match the variety of the disturbances: "only variety can destroy variety" (p. 207). Ashby's Law is not limited to any particular kind of system but is a general systemic principle. Assume that the system is in the desired state, and that a particular disturbance acts on the system. If *R* has a response for this particular disturbance, the desired state will be maintained in equilibrium. The system may be exposed to a variety of disturbances. Whether the desired state is maintained depends on the *R* providing responses that match these perturbations. The law may seem obvious and too simple to be true as a general law for controllability of any system; however, Casti (1985) shows how to relate the law to classical control theory for a single-input/single-output system and, furthermore, how that particular case may be generalized to a wider range of systems and situations.

The simplicity of Ashby's Law is, in a sense, deceptive. It prescribes a capacity of the regulator, but says nothing about how the regulator should be designed or how regulation is to be realized. The *sine qua non* of Ashby's Law is that it states controllability is a matter of dealing with variety. Beer (1984) applied the Law of Requisite Variety to management science: "Ashby's Law stands to management science as Newton's Laws stand to physics; it is central to a coherent account of complexity control" (p. 7-25). Along the same line, Waelchli (1989) argues that Ashby's Law "is also a root law of organizations. Manifestations of the law are everywhere visible in historical and contemporary management theory and practice..." (p. 17).

One may also measure variety as the logarithm of the number of states taken to any convenient base. If I multiply with the likelihood of each state occurring and the sum over all possible states is multiplied, it results in a measure that takes account of the different probabilities. One can obtain a measure of the same form as entropy and information. This measure of variety is entropic variety.

Consider a system that has to match the variety of its environment. The ranges of states in this variety have different probabilities of occurring. The *inherent* entropic variety is defined as the 'outspreadness' of this probability. Assume that knowledge is incomplete about the probability of the various states occurring, and the estimate is always conservative, in that the determinacy of the system in terms of the likelihood of the different possible states occurring is not overestimated. The perceived entropic variety is defined as the outspreadness assigned to the variety. The perceived entropic variety depends on knowledge about the system. It decreases as one obtains more information about the system and has as its limit the inherent entropic variety. The value of the information obtained depends on how much the uncertainty decreases.

The entropy in the system will change over time, but the variety of the controlling and controlled system must equate. If the regulator system does not have requisite variety, it must strive to amplify its variety or attenuate the variety of the controlled system. Therefore, a more complex system should become more manageable with improved availability and exchange of information. It is important to distinguish between that part of the variety which is caused by uncertainty and that caused by other properties of the system. The part caused by uncertainty represents a loss, whereas the part caused by other properties of the system can be used in a constructive way.

### 2.6.4 Beer (1985) and Complexity

Often, IT systems are designed without a clear examination of the workings of the organization they are intended to serve. This lack of foresight can easily lead to the automation of processes that do not meet the needs of that organization. Few think very deeply about what makes organizations 'tick.' This is probably because human beings are very easily conditioned to accept the social framework around them as though it was a part of the natural world.

The relation between complexity and controllability is that complex systems are harder to model and, as shown by Conant and Ashby (1970), the simplest regulator of a system is a model of the system it controls. This is not to say the model in the regulator must copy all the complex intricacies of the system. It suffices if the regulator has a model of the system's behavior. In many instances, only a sub-set of all theoretically possible states of the system and its environment are relevant for normal operation; thus, it is not necessary to model all theoretically possible behaviors of the system. In the past few years, 'complexity' has become a major buzzword, or, as Edmonds (1997) nicely phrases it:

> The label of 'complexity' often performs much the same role as that of the name of a desirable residential area in a real estate agent's advertisements. It is applied to many items beyond the original area but which are still somewhere in the vicinity. It thus helps in the item's promotion by ensuring that a sufficient number of people will enquire into the details, but that does not mean that this wider use is ideal if one wishes to perform a more precise analysis. (p. 1)

Stafford Beer (1972) developed the Variable System Model (VSM) over a period of more than thirty years as an aid to the practical process of diagnosing problems in human organizations and helping to improve their function. Beer believes that effective organizations should maximize the freedom of participants within the practical constraints of the requirement for those organizations to fulfill their purpose. Beer intends VSM as an aid to the diagnosis of organizational problems and the subsequent process of organizational re-design. The redesigning process should use technology, particularly information technology, to assist in providing organizations with a nervous system that supports their aims, without the burden of bureaucracy. Software projects often involve the management of a very high degree of complexity. All too frequently, complex issues are oversimplified to fit assumptions about how projects need to be structured. Once divided into 'simple' parts, work can proceed, with apparent progress. Unfortunately, when one attempts to integrate the parts near the end of the project, they discover that 'the sum of the parts does not equal the whole.' Viable systems invariably contain a number of operations, each with an associated management task that functions in its own environment. It is vital that all communication channels have requisite variety to handle transmissions. In practice, this means that policy has to be effectively communicated to each operational management, which then has to have the means for translating this into more concrete action plans to be followed by the operation. The operation then needs effective channels to its environment. A breakdown at any point will lead to ineffective action. This principle introduces a time element. Communication along the channels has to be fast enough to keep up with the rate at which variety is generated; otherwise, the system will become unstable. The stability of the system is dynamic, not static. Each entity in a self-organizing system has its own 'language' whenever a message crosses a boundary. Therefore, it needs to be 'translated' to continue to make sense. This process is transduction. If the transducer does not have requisite variety, the message is garbled or lost. Organization explicitly refers to the need for communication and response fast enough to keep up with the rate of changes affecting the organization.

To summarize, complex systems, as defined by Beer (1979), have many distinguishable components (variety, heterogeneity), which interact (connectivity) and are intricately dependent of each other. The number of system components is too large to treat them individually, but too few to treat them statistically. Their interaction is too complicated to divide the system without losing information and the components are too few for statistical treatment. In addition, any complex adaptive system has a medium number of intelligent and adaptive agents who act on local rather than global information. The macro system and its associated complexity is, to a degree, subjective in that it depends on the ignorance of the person examining it, and complexity is dependent on the framework in which it is considered. Thus, the task faced by the system designer is greater than the complexity faced by the operators.

Although the AOC is a military operational C2 node response to and provider of input into the open system of reality, Ashby (1948, 1956) and Beer's (1985) concepts provide understanding into why the AOC can be perceived as a regulator where the capability of the human organization (and not the technical infrastructure) should be maximized. Replicating an actual theater technical milieu, if theoretically possible, would be cost prohibitive. As all combat AOCs' infrastructures technically transformed over time, it is important to understand how any new box 'fits' within its various data chains. By incorporating a measure (Ashby, 1948; Beer, 1985; Conant, 1976) for information process, one may achieve the goal of repeatability. More importantly, a quantitative measure of information processing provides a hope of minimizing the human variable by putting the human in the background.

## 2.7 (PLURALISM) MENTAL MODEL AND LATTICE THEORY

What is known of the world outside the AOC is not what is depicted in displays on the wall in front of the operators, but the shared mental model in the minds of the operators. This mental model is formed from basic beliefs and what operators, as a group, perceive about reality. According to Mathieu et al. (2000), "mental models...help people to describe, explain, and predict events in their environment" (p.274). Ever since behavioral psychologist E.C. Tolman (1948) promulgated the phrase "cognitive map", this concept has been studied and adapted in disciplines such as cognitive psychology, behavioral geography, computer science, engineering, and neuropsychology. The term 'mental map' or model commonly represents the internal knowledge base of living data processors. Organization theory describes team mental models in terms of shared and/or tacit knowledge (Carley, 1997; Klimoski & Mohammed, 1994). Team members in any organization are more effective when they have the information needed to accomplish their tasks effectively. Individuals who self-identify as members of a team understand that they will only succeed if they are aware of the role and function they perform. While team members do share some forms of mental models and some harmonizing of situational awareness, they are individuals, and it is unlikely they are carbon copies of each other. Further, each team member has different tacit knowledge, domain expertise, and task responsibilities, and therefore cannot share the same mental model and do not need identical situational awareness. This interwoven situational awareness concept was developed and refined by Sonnenwald and Pierce (1998), who suggest C2 teams perform better when members develop an interwoven pattern of awareness of the milieu in which they operate, mixed with an awareness of what other team members see or ought to see.

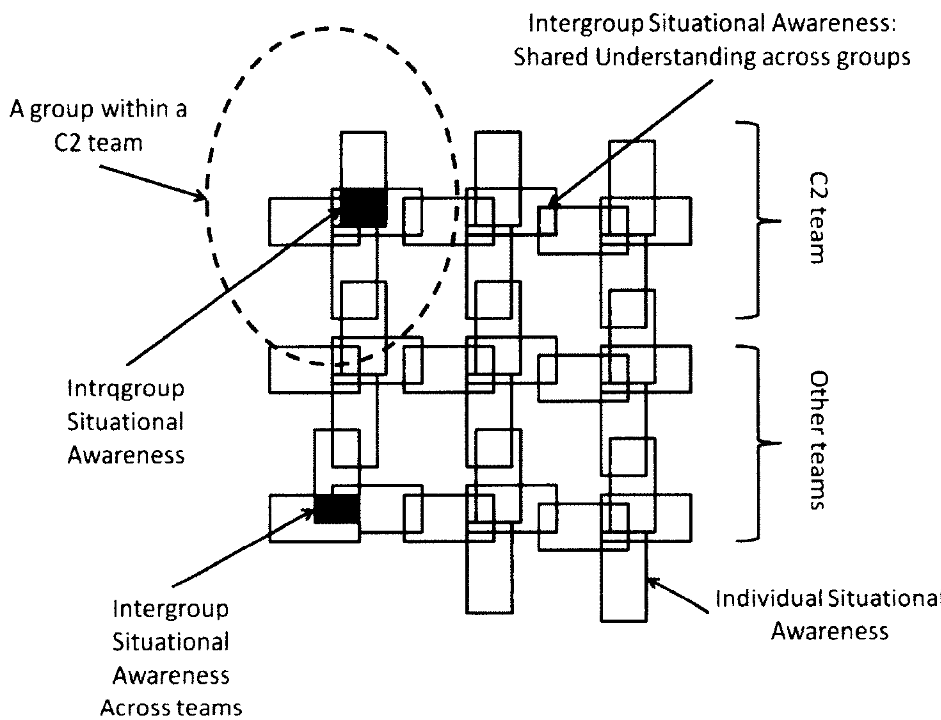



*Figure 15.* Modification of Sonnenwald and Pierce (1998). Interwoven Situational Awareness

Sonnenwald (1998) developed this concept further. She suggested that interwoven situational awareness may be composed of three distinct, but mutually reinforcing, types of 'awareness.' Environmental awareness involves recognition of the current state of activity inside the task environment. The task environment in this level of awareness is different for different tasks. For individuals with a narrow and specific task to perform, environmental awareness would be restricted to that particular task. For individuals with broader tasks that require them to interact outside a particular setting, environmental awareness includes both the physical environment and the combat environment in which the AOC is controlling forces. Domain or content awareness involves the individual team member recognizing something of importance to a particular task or conceptual area of responsibility. Interpersonal awareness involves an individual's sensitivity to what teammates think or feel, how emotions may affect performance on team tasks or processes, or preferred work and communications styles. Raw data or raw information flowing into the AOC have to be interpreted and understood by at least one person and communicated to add to overall group knowledge. Team collaborative work requires communication be completed between at least two individuals. The United States Army has looked at the communication process within teams on at least one occasion. A 1980 research effort studied verbal transmission of information between different echelons in a command group and found the percentage of information successfully transmitted and received seemed related to personality and position. The study focused on impact of individual communications style on team performance, but did not fully explore team information behavior itself (Kaplan, 1980).

In the conceptual work concerning the relationship between mental models, team performance, and situational awareness, researchers began to realize that, although possession of accurate mental models is a prerequisite for effective team performance and team situational awareness, it may not be sufficient. Specifically, researchers have argued that while members must hold accurate mental models, it is the sharing of mutual mental models among members – or shared mental models – that allows for effective coordinated and adaptive team behavior. Graham (2004) shows that this sharing is particularly critical if military units are to be adaptive. This sharing may be especially difficult in multinational teams because cultural differences place obstacles to information exchange that is required to develop these models. For example, a person from a culture with strong power distance beliefs may not feel comfortable presenting a skill set to a supervisor. Others (Craik, K. (1943), Ehrlich, K. (1996). Gentner, D., and A. L. Stevens, Eds. (1983). Johnson-Laird, P. N. (1983) Moray, 1990) have suggested using lattice theory to provide formalism for the knowledge base used as a mental model by operators. The ordering relation is interpreted as 'is caused by', so the lattice becomes a representation of the operator's causal hypotheses about the system. One can think of a given system causally in different ways (purposes, mechanics, physical form, etc.). Each alternative gives rise to a separate lattice. These lattices relate to each other and to an objective description of the structure and function of the physical system by homomorphic mappings, which is an extension of Aristotle's levels of abstraction. Errors arise when nodes on the mental lattices are not connected in the same way as the physical system lattice: when the latter changes so that the mental lattice no longer provides an accurate map, even as a homomorphism, or when inverse one-to-many mapping gives rise to ambiguities.

There have been few studies on how organizational knowledge compares to reality. Lattice theory provides a method to understand the group interaction. An objective lattice description of the real physical relations between the parts of the system as in engineering specifications expresses the interactions among physical components in reality. This lattice I will call the physical system lattice (PSL). Insofar as an operator's mental model is isomorphic to the PSL, just to that extent is it a complete model of the physical system, and just to that extent will the mental model's predictions exactly match the output of the different parts of the physical system when it is provided with system inputs and parameter values. In general, however, the operator's knowledge will be imperfect for at least two reasons. First, if the system is large, it may simply be impossible for the operator to scan and remember the displayed values of the system variables to acquire a perfect knowledge of the system relations. Second, and more importantly, the abstraction hierarchy suggests that, for many purposes, mental models will be homomorphs, not isomorphs, of the physical system.

The higher the level of the abstraction hierarchy at which a person thinks about the system, the fewer the elements to think about. A Group may contain several Squadrons. A Squadron will contain several Aircraft. An Aircraft may contain several bombs. Thus, it is advantageous for an operator to consider a system as high up the hierarchy as possible to reduce his or her mental workload and the amount of data he or she must carry in his or her working memory. The higher levels of the abstraction hierarchy are formed from the lower levels by many-to-one mappings that develop in formal training or informal experience. That is, higher levels of abstraction are homomorphs of lower levels. They preserve the causal relations between subsystems with a loss of detail. Suppose that different kinds of causes may give rise to different lattices. Each cause (formal, material, efficient, or final [that is, purpose]) can provide a complete description of the system in its own terms. These descriptions are complementary, not mutually exclusive. Each can be derived as a formal cause lattice [FCL], material cause lattice [MCL], efficient cause lattice [ECL] or purposive cause lattice [PCL] by an appropriate mapping from the PSL, and each has its own abstraction hierarchy. In practice, each will be defective in a different way. For example, one may know a particular circuit is present to provide cooling (final cause) and know what values of the display show that it is working and what controls switch it on or off (formal cause), but not know what mechanism is involved, or its underlying physical principles (material and efficient cause). In such a case, FCLs and PCLs will contain elements not present in MCLs and ECLs. These mental mappings and their effect on flow as described by Shannon (1948), Conant (1976), Ashby (1948), and Beer (1985) are poorly reconciled. These seminal authors use terms like "blockage," and other qualitative terms to deal with "abstraction". Mental model and lattice theory provides understanding as to why the technical picture displayed on the wall is not what an organization actually understands. It also defines why any human organization should not be assumed to be populated by automatons and that it will always change and morph, minute to minute and shift to shift. Mental model and lattice theory bring out the point that Ashby, Beer, and Conant's models strip away a majority of the complexity in humans.

### 2.7.1 Data Flow Model

One of the difficulties swiftly encountered in researching C2 is high variability in the quality of literature about the subject, as the writings may express an author's cogitative concepts about a wide range of subjects. Many writings are articulated with thoughts that are an 'inch deep and a mile wide' in quantitative or qualitative facts, which leads to near impossibility of repeatability as validation. Much of Western literature about military C2 is inductive in nature and uses only the principle of coherence, implying 'truth' based on metal ornaments, hard won, on the author's garments. Like any military command node, the AOC can be represented as a task model because positional functions are well understood and allow creation of operation sequence diagrams for deeper analysis. An additional function to understand in the role of the AOC is the underlying technical network. Understanding of the technical infrastructure requires examination from an information theory (origination, information flows, IT use, and information-worker productivity) perspective. Studies of IT-productivity demonstrate new technologies as well as adaptation to a different way of working that allow increased absorption of available information with a significant effect on individual and overall unit production (Aral & Weill, 2007; Bharadwaj, Bharadwaj, & Konsynski, 1999; Brynjolfsson & Hitt, 2000) by increasing asynchronous communication (Hinds & Kiesler, 2002). Information can reduce uncertainty (Cyert & March, 1963) or temper risk aversion behavior (Arrow, 1962; Stiglitz, 2000). When information is vague, it takes time to verify it by collection of additional data, thus reducing effective decisions (Hansen, 2002). All these factors point to a measurable chain, in which the initial data can be collected and analyzed. Information theory treats each human as an information channel, thus minimizing the factor of human variability. Applying this theory allows one to understand the infrastructure that moves data quantitatively. Is the electric representation of data on an accessible network? Is the format correct, can it be found, and, if found, retrieved? If retrieved, can it be understood? Do the additional data improve the effectiveness of the knowledge worker, or can he even use it? How does an information worker's understanding compare to that of the decision maker? A goal of this dissertation is to accomplish information flow analysis using quantitative data captured from a representative C2 node.

### 2.7.2 (Pluralism) Social Network

To understand the AOC, it is critical to examine the underlying supporting structure. Social Network Analysis (SNA) is an appropriate tool to evaluate the human networking side of C2. Social network theory looks at relationships in terms of links and nodes. Nodes are the individuals and links are a relationship between the individuals. There are many different ways people can be linked (face-to-face, e-mail, text chat, phone, meetings, etc.) and each interaction has an effect on the whole. The core assumption is that the relationship is the most important function. Social networking proposes individuals are less important than their relationships. Those relationships define a structure that can be studied, mapped, monitored, measured, and evaluated graphically or statistically to improve organizational outputs (Barnes, 1954; Granovetter, 1973; Milgram, 1967). A SNA study can prompt such questions as: "How does the actual organization compare to the organizational chart on the wall?"; "What paths are available for the information to flow?"; "Why does some information fall on the floor?"; "Is critical information not available?"; "How does the organizational structure change over time?"; or "Are increasing available paths resulting in C2 nodes taking on fewer closed-system characteristics?" SNA can provide both a visual and quantitative structure for analysis of complex human systems like the AOC, because it can be organized in mathematical terms and is grounded in the repeatable analysis of empirical data. These techniques have and can be used to understand diffusion of information, organizational behavior, the spread of disease, and other phenomena.

"Social Networks" is a term coined by John Barnes in 1954. Social Network Analysis seeks to understand the human interactions by looking at the people and their relationships within a specified social context. In Social Network Analysis, the primary data collected are on the relationship between actors (sometimes called points, nodes, or agents) with actor interactions collected as secondary data (often described as a link, edge, or tie) (Wasserman, 1994). The following overview is adapted from Hanneman and

Riddle (2005). Humans are depicted in the network diagram as a simple node, or point in space. A line connecting the two points represents an edge, the relational connection of the two people. Ties can be directional; if a person claims a relationship with the other person, an arrow connects the nodes pointing towards the flow of information. If both claim a relationship, then the information flow is bi-directional and direction can be annotated on each end of the edge (Figure 11):

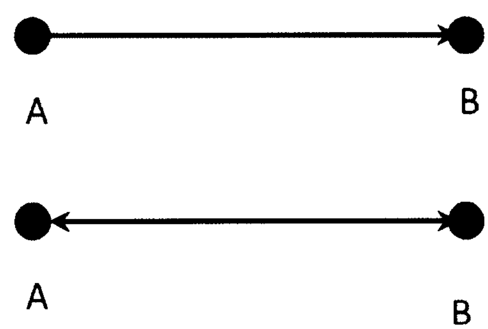



*Figure 16.* Examples of directional and bi-directional ties

The analysis involves an in-depth evaluation and comparison of edges at various levels: between two actors (also called a dyad), or among and between groups or clusters of actors (also called cliques), and among all nodes included in the selected network (Figure 12). The configuration of the network can influence the outcomes and characteristics of individual actors because their position in the network provides both opportunities and constraints based on their relationship and interactions. Changes in the pattern of relationships change the structure of the network and in turn can change the outcomes.

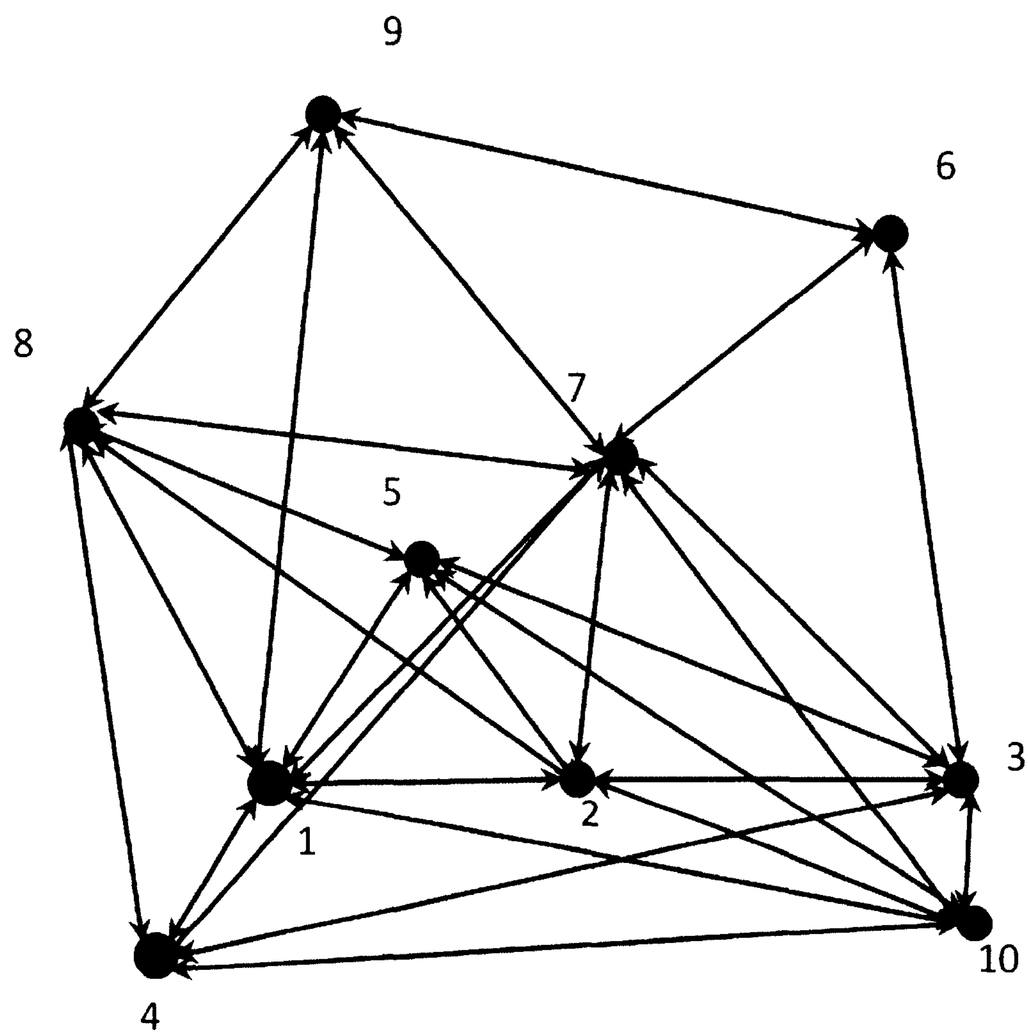



*Figure 17.* An example of a network diagram (Modification of Hanneman & Riddle)

The data collected may also be used and displayed in a matrix algebra format since the information is sometimes more understandable than it would be in a graphical form. Figure 13 is the mathematical representation of Figure 12. Traditional statistical measures of social networks are often constructed in an algebraic format for quantitative purposes.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 |
| 2 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 |
| 3 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 |
| 4 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 |
| 5 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 |
| 6 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 |
| 7 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| 8 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 0 |
| 9 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 |
| 10 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 |

*Figure 18.* An example of a network matrix (Modification of Hanneman & Riddle, 2005)

Ties, edges, and links can also have values. Binary data (such as yes/no questions) are represented by the presence or absence of a tie. Valued data (such as "on a scale of 1 to 7") give information on the strength of an edge. A social network perspective is, inherently a multi-actor perspective. Social Network Analysis can offset the limitations of static organizational block diagrams (Serrat, 2009). In most cases, the trend will be to have narrow numbers of strong ties and large numbers of weak ties. This is most likely true because humans have limited amounts of time and energy, and strong relational ties require continued nurturing. Social structures can also develop a stable framework with only a limited number of strong connections.

Social Networking defines the ability to create different organizational structures that can be compared and contrasted. If the Social Network structure is static, it then defines the courses and paths that are available for information flow.

### 2.7.3 Measures

To understand networks well, the community uses a common set of measurements. Key terms include:

- *Distance* - in a network $d_{ij}$ between two nodes (dyads), labeled i and j respectively, is defined as the number of edges along the shortest path connecting them.
- *Diameter* - the diameter (often described with the term "D") of a network is the maximal distance among all distances between any dyads in the network.
- *Average path length* - the average path length "L" of the network is the mean distance between two dyads, averaged over all pairs of nodes.
- *Characteristic Path Length (CPL)* - the median of the average distance from each node to every other node in the network, CPL is useful in determining the diffusion rate of the network; the shorter the CPL, the quicker the information transfers throughout the network. In a social network, for instance, L is the average number of people existing in the shortest chain connecting two friends. I should note the average path lengths of most real complex networks are relatively small.
- *Density* – this is the proportion of observed relationships among all possible ties, edges, or the interconnectedness of a network. A higher density score reflects more ties, which one may interpret as a more coordinated network with more opportunities for sharing of information and resources among network partners.
- *Clustering Coefficient* - helps describe the clustering of the network. The clustering coefficient, C, is the average fraction of pairs of neighbors of a node that are also neighbors of each other. Suppose that a node, i, in the network $K_i$ has edges and they connect this node to other $K_i$ nodes. These nodes are all neighbors of node i. At most $K_i (K_i - 1)/2$ edges can exist among them, and this only occurs when every neighbor of node i is connected to every other neighbor of node i. The clustering

coefficient $C_i$ of node i is then defined as the ratio between the number of edges $E_i$ that actually exist among these nodes $K_i$ and the total possible number $K_i (K_i -1)/2$, namely, $C_i = 2E_i / K_i (K_i -1)$. The clustering coefficient C of the whole network is the average of $C_i$ over all i. If and only if the network is globally coupled, which means that every node in the network connects to every other node, then $C_i = 1$. Most large-scale real networks have a tendency toward clustering, in the sense that their clustering coefficients are much greater than 0, although they are still significantly less than one (namely, far away from being globally connected).

- *Reciprocity* – while density simply measures whether or not a relational tie exists, reciprocity measures the direction and strength of that tie. For example, A nominates B as a partner with whom they have a strong relationship, and B may also nominate A as a partner with a strong relationship, indicating reciprocity. Conversely, B may not have the same view of the relationship and gives a lower rating or does not acknowledge a relationship with A. If they rate each other similarly, then they will have a high reciprocity score. Scores for this measure are proportions that range between 0 and 1, which are expressed as percentages in this report.
- *Indegree Centrality* – actors who have more ties have more opportunities because they have more access to network resources. Indegree centrality is the number of ties an actor has 'in-coming' from other actors. These incoming ties indicate network partners who are seeking a connection with the actor and therefore represent an actor's importance in a particular area.

- *Neutrality rating* – a measurement of the amount of additional latent structure in a complex network. This additional latent structure, where properly configured, is the source of networked effects, adaptability, and modularity in complex networks.
- *Nucleus* – a region of a social network with the highest concentration of links between nodes.
- *Fringe* – a region of a social network with a low concentration of links between nodes.
- *Betweenness Centrality* – betweenness is a common measure for diffusion of information in a network and denotes an actor's value in communication. An actor with a high score lies between other actors and provides the shortest path between those other actors. If an actor with a high betweenness centrality were removed from the network, it would hinder communication between the remaining actors.

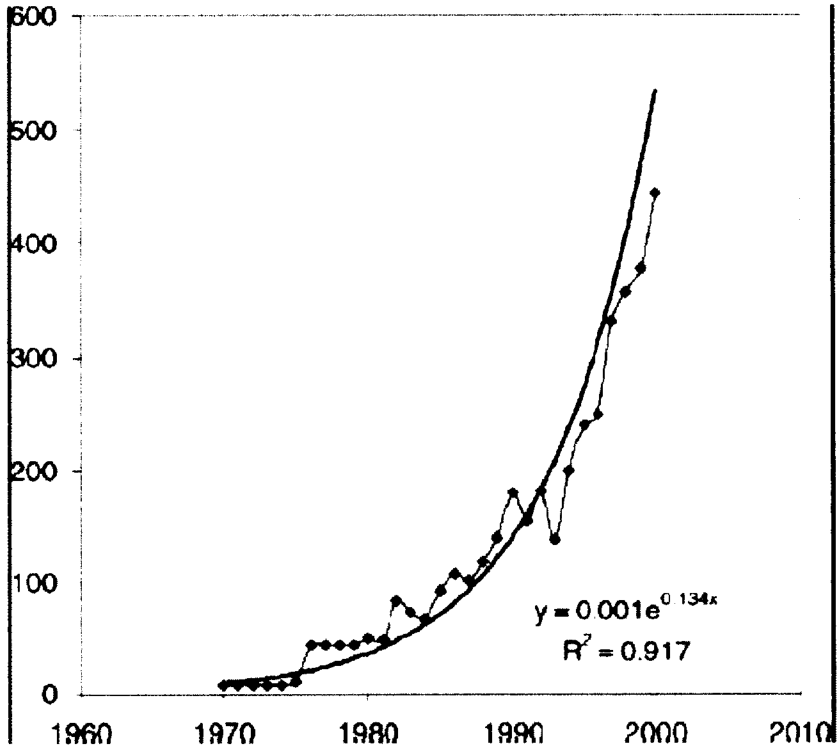
**2.7.4 Asymmetric and Symmetric Data Flow**

Human-to-human interaction will always be able to be categorized as asymmetric or symmetric in time required to accomplish the interaction. Symmetric communication may be as simple as some yelled words from the person sitting at the computer next to another or as asymmetric as a senior leaders reading about Troy. Symmetric communication could include media like voice, radio, text chat and web services, which result in minimal time (in human terms) between sending and receiving. Asymmetric communication includes anything with a human desirable time difference: books, magazines, e-mail, and web-pages. For pithiness, I will examine text chat as a nominal example of symmetric communications.

The biggest difference in walking into an AOC 20 years ago and today is the noticeable lack of ringing telephones as an indicator of current intensity of the operation. Text chat has become a primary tool of ongoing military operations. Despite the hindrance of current military command, control, and communications (C3), to a hear to a classic Napoleonic hierarchy, information revolution values strategically enable principles like Net-Centric Warfare, and challenge the status quo. Interaction by text chat across various networks is fast becoming a standard form of communication (Teredesai, et al., 2004). Industrial and governmental organizations are very interested in understanding the nature of broad knowledge-sharing networks that exist within their organizations. In recent conflicts in Afghanistan and Iraq, the Text Chat application of choice in the battle arena and many Department of Defense (DOD)/Intelligence Community facilities is Mardam Internet Relay Chat (mIRC). mIRC is a Windows Internet Relay Chat (IRC) client application written by Khaled Mardam-Bey. Although it has not been approved for use within the DOD, Air Force and Air Operations Center (AOC) organizations worldwide want to use it as a collaborative tool. Few understand how mIRC succeeds as an 'information revolution' text chat tool viable for military use. It creates a powerful collaborative virtual environment in very low bandwidth that allows operators on robust communications to commune with fielded warfighters on disadvantaged communications. mIRC chat servers in Bahrain create a cyber community of over 2700 ongoing conversations in one Regional Combatant Commander's area of responsibility. Reportedly, over 1253 joint organizations exchange textual information via the Bahrain mIRC servers. Operators share a physical connection to a common network (SIPRNET) on which these servers are located. Two information revolution principles demonstrated for the first time in recent conflicts are military action offices (AOs) 'swarming' in cyberspace to quickly solve emerging problems, and the 'flat earth' model of decision making, in which AOs are empowered to make or coordinate decisions rather than forcing information up the classic Napoleonic hierarchy for processing. Despite lack of formal approval, mIRC has been used in the field and gained notable acceptance. Continued use does present a number of risks and raises concerns. One significant issue is that mIRC is shareware, not freeware. The software is so essential that lack of formal approval from DOD or the developer and questions of security are considered a negligible risk. Justification for continued use is difficult, as free evaluated IRC chat clients and evaluated commercial chat software have been used successfully in wartime operations. Text chat capabilities can significantly enable military members to perform most office-oriented and operational communication tasks from their desktops. Collaboration capability is tied to a central military goal of empowering end users by channeling the information flood into a reservoir for enterprise-wide decisions. Chat has had a huge impact on the tactical war fighter. Everything from mission planning to execution often is taking place today without a single radio transmission; debriefs from Operation Iraqi Freedom confirm this. The technology that permits this to take place is growing, but the policies that support the use of this capability have not kept pace. It is not unusual to find the official policy in a battle group or joint task force for use of chat to include comments such as, 'Chat will be used for administrative decisions only; all orders for execution will be confirmed via voice circuits.' The policy rarely is followed. The problem is not with the use of chat, but with the fact that operators are working in a gray area of how to best use the newest technology.

I will examine web page use (posting and pulling) as a nominal example of asymmetric communications. CW2 Jason Cord, in his article, Fury Ring Addresses Knowledge Management and Dynamic Information Flow Process states, "a user will most likely check their e-mail multiple times a day, but only visit the portal [web page] a couple times a day" (p. 35). One should remember web pages are only one component of the entire C2 structure. There are a large number of other computer-based asymmetric technologies available including e-mail, recorded information, Wikis, and web logs, which represent communication disjointed in time. At present, military communications systems have limited capabilities, and most of the time operate in fixed configurations. It is appropriate to represent the current limited capability, fixed configuration as a web page where all agents can 'read'(pull) information, but only members belonging to an organization with a web page can 'upload' (post) acquired or developed information.

AOC quantitative data can be captured and analyzed supporting SNA. When a collection of cabled computers couples people by text chat, e-mail, or other application, there is a social network. SNA describes that human pattern and sees how those relationships affect the output and outcome. The networking approach encourages understanding beyond any single pair of interactions. SNA is well understood and used across many different communities.




**Exponential growth of publications indexed by Sociological Abstracts containing "social network" in the abstract or title.**
**(Source: Borgatti and Foster, 2005)**

*Figure 19.* SNA Growth

SNA should be as ubiquitous as a bottle of ketchup at the nearest greasy spoon in analyzing C2 systems. The AOC is qualitatively efficient and accurate in planning and execution. The quantitative approach of SNA may have potential to improve efficiency, accuracy, and specificity in operational planning and tactical delivery of air power. Historically, the nature of organized conflict changes as the milieu of participants change. The wars of an agrarian society in the time of Charlemagne differ from the industrial conflicts of the 20th century. Human nature has not changed. As society moves from land-centric, to machine-focused, to knowledge-salient, victors and losers persist. A plumber derives the facts in his universe from his hands, eyes, tools, and knowledge. Supervision three or more levels above the person with their hands on the problem does not deal with reality, but with extracted perception of it. Social networks transmit this perception. This is the cosmology of C2. One must examine tactical assumptions about the current organizational structure from multiple perspectives, and SNA can be one of those views.

In effect, the primary task of transformation is to increase the level of performance of a complex system. This 'transformation' is certainly a function of resources. However, it is also dependent on the method(s) that guide thinking, decisions, actions, and interpretations to support transformation within allocated resources. Therefore, approaches that are more sophisticated might alleviate the difficulties associated with transformation and more effectively allocate scarce resources (Keating, 2003).

## 2.8 CONCLUSION FROM THE LITERATURE REVIEW

The entire assumption of the military science of C2 is based on the belief that we can deliberately organize to solve problems more efficiently. This review resolves that it is appropriate to conduct an analysis of a representative Air Power Operational C2 node using a case study designed to elicit fundamental understanding, thereby using a method to determine how a representative AOC C2 system changes varying noise and system fragmentation (C2 fundamental understanding) when operating in either a Nominal or Edge organizational construct.

The literature review, not being historical in nature, opens itself up to scrutiny because the authors and 'facts' have been cherry-picked. I have tried to take broad slices of fields to build a lens to observe operational C2. Polanyi (1983) articulates CST in this way:

> I am looking at Gestalt as the outcome of an active shaping of experience preformed in the pursuit of knowledge. This shaping and integrating I held to be the great and indispensable tacit power by which all knowledge is discovered and, once discovered, is held to be true. (p.36)

From this literature review, it is relatively easy to see the seminal authors in both IT and Social Networking form two schools of thought. The IT school of thought deals more with machine themes and would be made up of authors like Shannon (1949), Ashby (1948), Beer (1985), Conant (1976), Sommerhoff (1950), Brillouin (1962), Nørretranders (1991), and Waelchli (1989). Some of the authors only deal with mechanical themes, but they all try to solve fundamental human problems. The other school of thought is led by authors that are concerned with human/organizational themes. This school consists of authors like Mathieu (2000), Carley (1997); Klimoski & Mohammed (1994), Sonnenwald and Pierce (1998), Kaplan (1980), Graham (2004), Barnes (1954), Hanneman (2005), Granovetter (1973), and Milgram (1967). Using CST, I have identified that between these giant schools of thought there is a much smaller school of authors that write about themes that bind both the machine and the human themes, attacking both problem sets together. These authors consist of thinkers like Bharadwaj and Konsynski (1999), Brynjolfsson and Hitt (2000), Aral and Weill (2007), Hinds and Kiesler (2002), Cyert and March (1963), Arrow (1962), Stiglitz (2000), and Joslyn and Rocha (2000). A graphic depiction of the three schools is as follows:

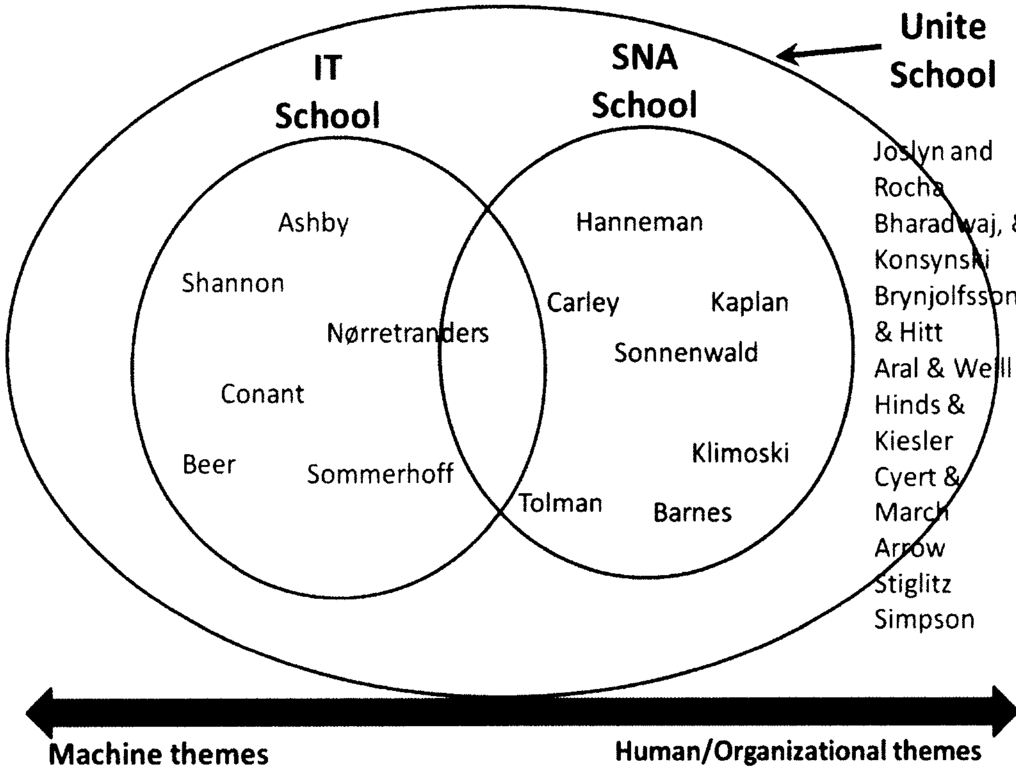



*Figure 20.* Relationship of Schools of Thought

By using CST as major inquiry method, I am able to identify major themes in the literature (i.e. machine themes, human/organizational themes, and authors that synchronize the knowledge learned from both). In addition, I am able to critique the literature on how the thoughts of the writers relate, and I have been able to identify gaps in the knowledge base (i.e. not a well-developed body of literature that point in the waypoints, fundamental C2 discoveries, nor expected future developmental philosophy for C2 systems).

# CHAPTER THREE - RESEARCH DESIGN

This chapter will describe the methods and procedures applied for creating a C2 model and analyzing the data for this case study. This chapter will include a discourse of the research Case Study technique; an examination of the data collection method; an exegesis of the data analyses; trustworthiness and validity of the method; an appraisal of the study's significance; and, finally, a chapter summary.

The purpose of this case study is to examine and compare two organizational C2 structures when subjected to increasing noise and system fragmentation.

## 3.1 RESEARCH TECHNIQUE

According to Eisenhardt (1989), case study research can be defined as "a research strategy which focuses on understanding the dynamics present within single settings" (p. 534). The AOC defines a single setting. Therefore, the use of the case study method is appropiate to use in researching fundamental airpower C2 issues. Yin (2003) notes case study methods may be involved in three roles: exploratory/descriptive studies, evaluation studies, and/or hypothesis testing. Exploratory and descriptive case studies (this dissertation is nominally binned into this category) examine the characteristics of some sort of extraction of reality with the hope of developing elicitation of input/output or cause-to-effect affiliations. The evaluation case study methodology proposes identifying potential explanations for a documented result that has already happened. The result could be either positive or negative; in either case, the goal is to understand what caused it.

### 3.1.2 History of Case Studies

The use of the case study method has a history of on-again, off-again use. It is generally believed the case study research method originated in France in the early 19th century as a method to accomplish social science research. Early American use of the method is most closely associated with the Sociology Department at the University of Chicago, where Robert Park, an ex-newspaper reporter and editor, led the charge and used it extensively. Around 1935, there was a desire for the study of Sociology to move toward a more scientific approach using associated quantitative methods, leading to a period of less use of the case study as a research method, and an increase in use of the survey method. Influential researchers in using the method include Campbell (1975), Lincoln and Guba (1985), Platt (1992), Smith and Pohland (1974), Stake, Easely, and Anastasiou (1978), Stake (1995), and Yin (1992).

Even in the early use of the case study method in Sociology, there was controversy and detractors. The members of the Sociological Positivists' school of thought wanted stable laws defining social interactions and considered the case study method as un-scientific. The members tended to consider proof only when quantitative methods could produce statically valid generalizable laws. Disputable issues then and today continue to center around reliability, validity, sampling, data collection, analysis, and generalization of the results. There is no consensus on what a case is or what a case study is not because the practice exists across a broad expanse of disciplines. Yin (1994) may provide the most commonly accepted definition when he writes:

> A case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between the phenomena and context are not clearly evident. [It] copes with the technically

> distinctive situation in which there will be many more variables of interest than data points and as one result relies on multiple sources of evidence, with data needing to converge in a triangulating fashion another result benefits from the prior development of theoretical proposition to guide data collection and analysis. (p. 13)

Case study research creditability often centers on the similar terms of reliability, and validity. Validity and reliability often have overlapping meanings. According to Martyn Hammersley (1990), validity refers to how accurately an account can represent a social phenomenon, and reliability is a matter of degree of consistency of observed objects (1992). To counteract integrity problems with this creditability issue, researchers (Miles & Huberman, 1994; Reige & Nair, 1996; Yin, 1989) have developed five approaches: construct validity; conformability; internal validity/credibility; external validity/transferability; and finally, reliability/dependability.

a) Construct validity ensures adequate operational measures for the concepts under investigation (Emory & Cooper, 1991; McDaniel & Gates, 1991).

b) Conformability is the ability of others to satisfy themselves that the research was carried out as described by the researcher (Lincoln & Guba, 1985; Miles & Huberman, 1994; Riege & Nair, 1996).

c) Internal validity/credibility is defined as the causal relationships between variables that may influence other variables (Emory & Cooper, 1991; McDaniel & Gates, 1991; Miles & Huberman, 1994; Zikmund, 1991).

d) External validity/transferability is the scope to which the findings can be replicated, or, in other words, generalizability (Emory & Cooper, 1991;

Lincoln & Guba, 1985; McDaniel & Gates, 1991; Miles & Huberman, 1994; Yin, 1989).

e) Reliability/dependability is the ability of other researchers to carry out the same study, with similar results (Cassell & Symon, 1994; Emory & Cooper, 1991; King et al., 1994; McDaniel & Gates, 1991; Miles & Huberman, 1994; Singleton et al., 1993).

Sampling is not random when using a qualitative approach such as a case study. Often truly random sampling cannot be used in case study research due to the inability to differentiate the special from the general among random chosen objects.

To study the C2 air power effectively, I needed a research design that allowed for a high degree of perturbations within a research range, as the important variables are not all known at the start of the investigation. According to Yin (2003), case studies are an appropriate method for this type of research. The purpose of Section 3.1 was to review the value of the case study method as a useful technique for the understanding of an operational airpower C2 node. I attempted to achieve three goals: first, define the exploratory case study; second, provide examples of model based exploratory case studies accomplished by others; and finally, defining the shortcomings and examining the limitations of the technique (note that this section will not examine the techniques for the design and reporting of case study research). The design and reporting results are well defined in case study literature (Feagin, Orum, & Sjoberg, 1991; Stake, 1995; Yin, 2003). Instead, the focus of this section is to show how a 'good' model-based case study can be an appropriate substitute for the analysis near impossible to obtain by primary data or the analysis of secondary data.

There are three basic methods to accomplish case study research:

1) Survey – as defined by Robson (2002) as a "collection of standardized information from a specific population, or some sample from one, usually, but not necessarily by means of a questionnaire or interview" (p.228);

2) Experimentation – the choice of this dissertation research as defined by Robson (2002) as "measuring the effect of manipulating one variable on another variable" (p. 110) (in this case, the variables are the technical infrastucture network and human command network);

3) Action research — where the observer is involved in the change process. To be consistent, Robson (2002) defines the purpose of action research as "influenc[ing] or chang[ing] some aspect of whatever is the focus of the research" (p. 215).

Exploratory case study method is designed to find the answers to questions posed by the study. The questions for this dissertation are well defined and within range of the proposed research. An additional reason investigative case study is an appropriate method for Air Power C2 has been expounded by Abramson (1992) due to the uniqueness of the data:

> since such data are rare, they can help elucidate the upper and lower boundaries of experience. Second such data can facilitate...prediction by documenting infrequent non-obvious, or counter intuitive occurrences that may be missed by standard statistical (or empitical) approaches. (p. 190)

Exploratory case study research is not a random sampling of a system being examined, as asserted by major researchers in the field, including Yin (2003) and Stake (1995).

Selected cases must be designed to maximize knowledge acquisition during the time period and within the resource constraints of the particular study.

As mentioned, exploratory case studies have been used by others, such as in the 1997 RAND Weapons Mixed and Exploratory Analysis by Arthur Brooks, Steve Bankes and Bart Bennett. In the RAND introduction, they define an exploratory analysis as a method to help comprehend complex systems such as combat models which may have imperfectly known parameters, decisions, and measures of effectiness. In a model-based exploratory case study, the model is run at many different input levels. In this case, the noise and system fragmentation are increased stepwise. Just as in the RAND study, in this exploratory model, a relatively large set of scenarios and conditions are set and their outcomes are observed. Various communities are undertaking case study using modeling. When conditions in any community preclude building the target system, modelers must make assumptions about their systems' details and interworkings. The resulting model is not a one-for-one representation of the real world, but it can provide insight as to how the world would behave if the modelers' assumptions are correct. Computational experimentation case studies are commonplace (Anderson, 1988; Campbell et al., 1985; Lipton, Marr & Welsh, 1989; Rose & Dobson, 1985; Strauss, 1974).

Case studies have well-recognized disadvantages. Even seminal authors such as Yin (1984) state that, "too many times, the case study investigator has been sloppy, and has allowed equivocal evidence or biased views to influence the direction of the findings and conclusions" (p. 14), decrying case study research that lacks academic rigor. In addition, scientific generalization resulting from case study research, in particular research using a single case study method, is very problematic. As Yin (2003) writes, "How can you generalise from a single case?" (p. 10)

In addition, Tellis (1997) criticizes the single-case exploration method for its difficulty in producing generalized conclusions. However, Yin (1993) notes that defining the parameters and setting the objectives in the research are more important than a large sample size. In my attempt to meet Yin's research standard, I used a single model to set the design parameters, and utilized a sample size larger than a single run (case). The third general criticism of case study research method is that the reports are too long, with mountains of data that are not well-managed or organized systematically for readers' understanding (Yin, 1984). This criticism often points at case studies that are ethnographic or longitudinal in nature. Air Power C2 case study will be a comparison case study and longitudinal issues are not expected be encountered.

Many researchers have also criticized case studies for failure to adequately account for measurement of dependent and independent variables, lack of defining a control, and arbitrariness in defining the results of the work (Campbell and Stanley, 1966; Carlsmith et. al., 1976; Kazdin, 1978; Kratochwill, 1978). *Command and Control in the Information Age* will mitigate these criticisms by accomplishing sensitivity analysis of the ELICIT model to understand the relationship of the variables, accomplishing well defined comparison of independent runs, and defining the results of the work through binocular lenses of Information Theory and Social Networking theory. Yin (2003) states:

> the case study inquiry copes with the technically distinctive situation in which there will be many more variables of interest than data points; ...relies on multiple sources of evidence, with data needing to converge in a triangulating

> fashion; and …benefits from the prior development of theoretical propositions to guide data collection and analysis. (p. 2)

My case study approach has been a comprehensive research strategy where I develop a conceptual framework, design a compressive model, collect predefined data, and analyze the data through my developed framework.

## 3.2 CONCEPTUAL MODEL

A conceptual lens of information flow in an AOC provides a sieve to extract from reality the data needed to accomplish a valid analysis. Information theory work has been accomplished in conjunction with nuclear power plants using Conant's model as a tool for describing human information processing (Kim, Soong, & Poong, 2003). Understanding paths and flows of information should give some indication of where there is sharing or blockage of information. The interaction of the human and technical networks should also suggest where and how knowledge leading to a decision comes about. The sharing of information could be the result of some path of communication between nodes (individuals/organizations) or through use of common screens of technically presented information. I will not analyze all five AOC divisions due to required resource expenditure.

The Man-Machine Interface (MMI) is where Beer (1986) defines the point at which the message crosses a boundary where it is "translated," or undergoes transduction to continue to make sense. To meet tomorrow's challenges requires knowledge, not only of the physical capacity of individuals and the team, but also cognitive capabilities and tendencies. The consequences of ignoring the cognitive function of the MMI are evident in failure. The ultimate objective is to model the cognitive behavior of the operators of the AOC to improve macro system design. To accomplish this analysis, it is important to develop a very detailed operator model in which operator incongruity can receive particular emphasis. An operator centric model should suggest several aspects that will be important in designing to maximize human team abilities in accomplishing complex tasks. Systems like the AOC, which involve loosely coupled IT decision support systems, need to be designed and maintained to maximize supporting human cognitive skill.

Scholars have debated for years about the capacity of decision makers to make major changes in direction from prior decisions at both individual and group level. One group of researchers stubbornly assumed the "rational human" actor. Another argued substantial change is rare, as indicated by the conservative nature of decision-making. In this view, stasis becomes the characteristic state of organizational and individual decision-making. In this static view, there are strong disincentives to decisions that depart substantially from the status quo (Lindblom, 1959). In the real world of military decision–making, disincentives render large departures from the norm rare and dangerous. Those who dispute this stable argument model often point to examples of changes resulting from 'basin of stability' change when the 'logical human' argument had some sway. Many government policy areas seem to have experienced large changes; recent examples would include the space program in the 1960s and military budgets after 9-11. This dissertation assumes incremental decision-making is the appropriate model.

Before describing a single channel decision flow, it is necessary to describe potential characteristics of operator behavior within an artificial representation of reality. Wood and Roth (1986) have summarized the characteristics of human operator behavior for nuclear power plants as the following, which they propose as a proxy for a Combat Operation division:

(1) Need for continuous monitoring or tracking of how disturbances develop, rather than a single diagnosis.

(2) Team must revise responses, based on a changing assessment of the situation, including the mental model of the expected dynamics of reality.

(3) How one sees the situation at any point depends, in part, on how they and others have perceived the event up to that point.

(4) Need to anticipate what could happen and, therefore revise monitoring strategies.

(5) Situation requires incremental decision-making with repeated inspection of the process and adjustment of the problem solutions.

(6) Adequate feedback is essential.

These qualities provide evidence that a contextual model is better able to describe overall team dynamic behavior than a sequential or workflow model. Workflow sequential models have difficulty describing continuous observations with revisions resulting from unanticipated responses with an uncertain outcome. Most workflow models are unidirectional sequence processes with stimulus input results in some response output. Conversely, contextual models can show flexibility and emphasize the comparison between a set sequence of processes and a choice of processing as a function of overall context. L. Bainbridge (1997) has described the details of the differences between the two models. **Error! Reference source not found.** 21 shows a proposed overview of the information processing model for warfighters in combat operations. In the proposed model, any operator is represented as an information-processing channel of multiple stages. Three stages will be required for any problem: Information Acquisition, Identification, and Diagnosis.

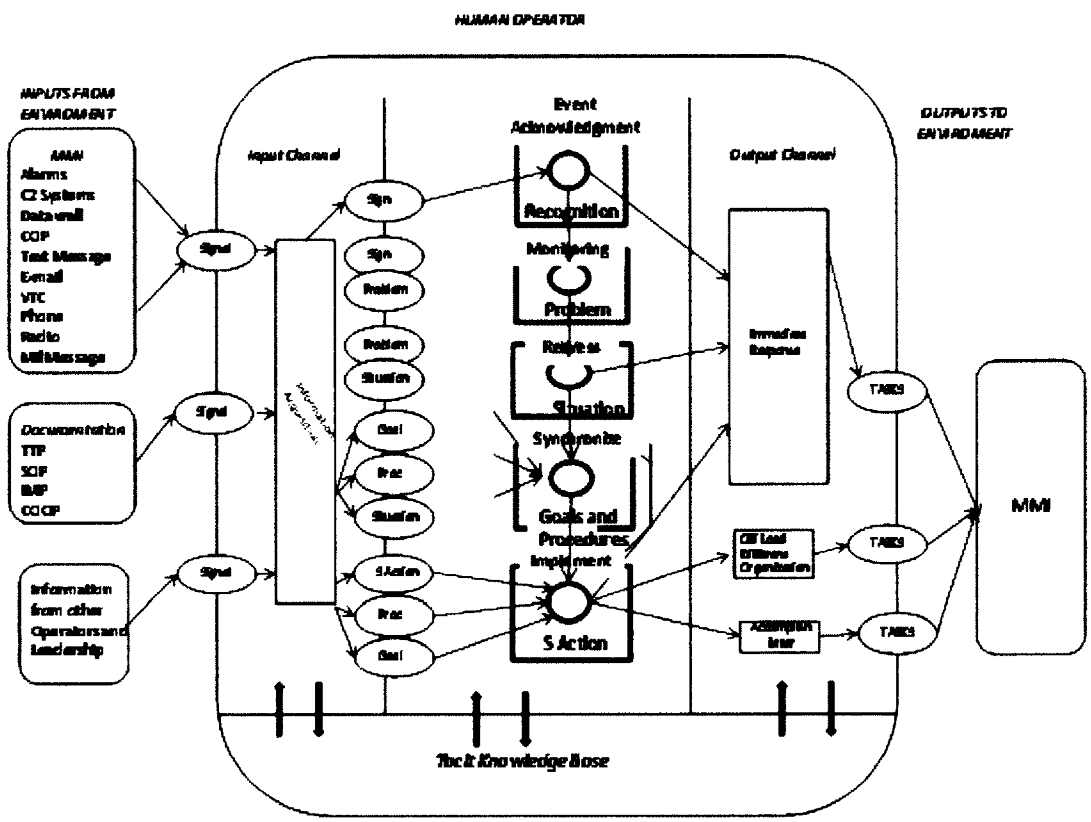



*Figure 21.* Overview of Information Processing Model

The stages of information processing are depicted by rectangular boxes. Circles depict the input or output of information of the stage. Any input or output actually is to be included at the appropriate stage since the information process is carried out in the stage (the drawing is constructed as a simple visual conveyance device for the concept). The arrows represent flow of information (in this case factoids). Arrows show backflow that represents the movement to previous stages. Backflow arrows do not convey information.

In this case, backflow means the operators retrograde to a previous stage and information already acquired and processed in the current stage is temporarily stored in their working memory or forgotten (Conant's term would most likely be blockage). The model shows process sequence as well as the information flow internally processed by the operator. By describing how information is integrated and reduced in stages, the model provides better elucidation. The same model can represent asymptotic performance or something less than standard without defining individual failure. The model can also convey various flows created from constrained extraction of the theater air power open system. In the propose process, inputs are matched with the operator's tacit knowledge or mental model and transformed to another type of output. Information at this stage could undergo a higher level of abstraction. If the data blob is not matched or is validated as irrelevant it may just 'fall on the floor' (blocked).

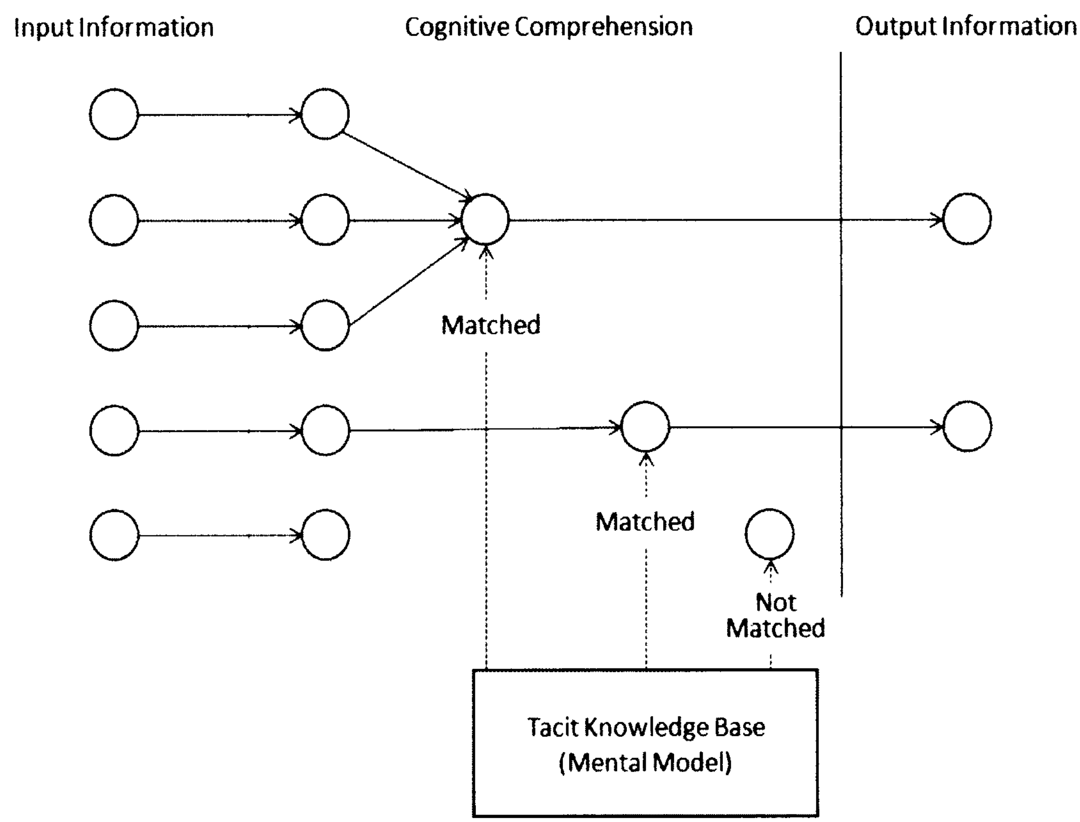



*Figure 22.* Information Matching Model

To better understand the proposed model, certain terms need to be defined. The definitions in Table 4 should be used as reference.

*Table 4.* Definitions of the transformed information

| Information | Definition |
|---|---|
| Signal | Information that exists in the environment or is provided by the external reality<br>Set of indicators and/or alarms or verbal messages from other operators<br>Sensory data presented on an individual client workstation<br>Certain features in the environment and the connect condition |
| Sign | Specific meanings about signal and significant or meaningful information |
| Problem | Warning information notifying occurrence of some unanticipated change in environment |
| Situation | Perceived state of the overall air power<br>Information related with a change of reality & the perturbation that produced the anomaly |
| Cause | Information about the anomalies and the root causes |
| Goal | Ultimate objective of actions carried out in response to anomalies |
| Procedure | Steps to follow for problem solving<br>Written or memorized process to be performed in order to achieve a goal |
| Schedule an Action | Series of actions chosen and scheduled according to the procedure |

Information acquisition is capturing data available at pickup points with the probes that are in place. An example of this process is Airborne Warning And Control System (AWACS) (pickup point) using airborne radar (probe) to create a COP track (data displayed in the AOC). The first step captures data available from the external environment. At this time, the warfighter must correlate raw data (AWACS generated track) to understand the logical and physical variables of their externally provided inputs that create their perception of reality. Tacit assumptions provide cognitive meaning of the signals provided. The operators can create many types of information as output. Members of Combat Operations can receive symmetric communication as a sign from individual computer screens, verbally from another team member, via the Ultra-high Frequency (UHF)/Very High Frequency (VHF) radio, over one of several telephones, or chat screens. Members of Combat Operations may also receive asymmetric communication as an e-mail, a message, or another publication. The operator can transform the signal information to start to describe a problem, a situation, or a cause. Figure 15 provides a visual depiction of information acquisition.

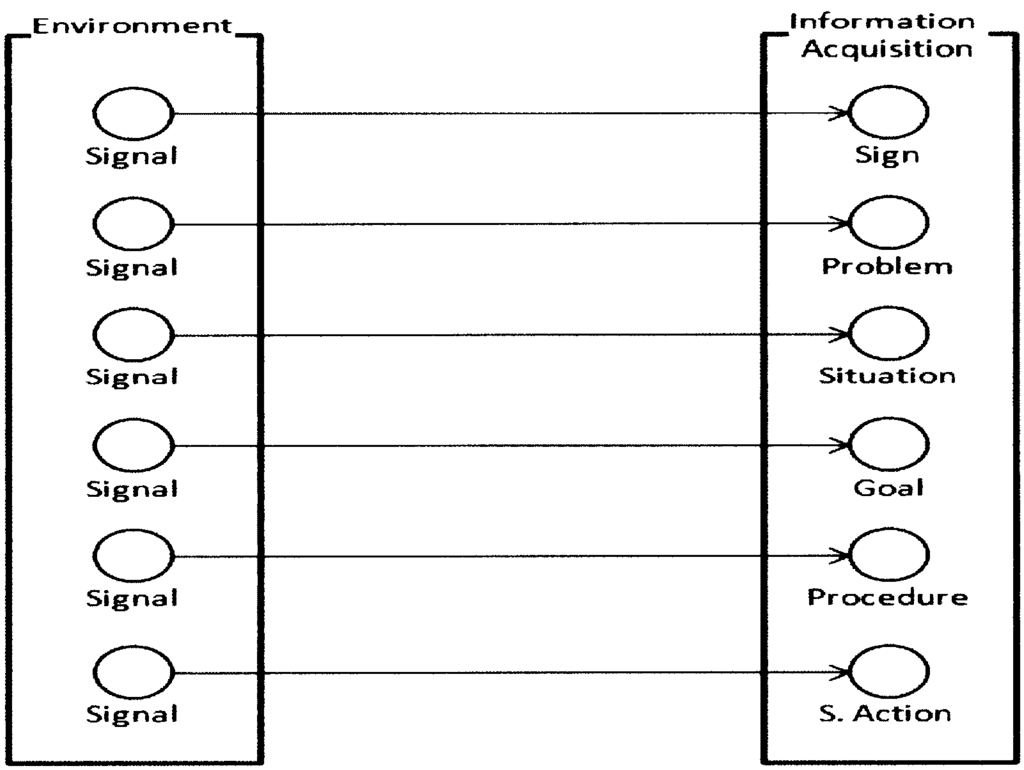



*Figure 23.* Information Acquisition

Information monitoring is the result of information acquisition. Monitoring accrues when normal (anticipated) or abnormal changes in the milieu cross the level of perception, and should be acknowledged if important enough. This is the point at which cognitive activity and working memory cross and it is the traditional step after information acquisition. If the event is not acknowledged, it will often be assumed to be background noise and could easily 'fall on the floor,' or in Conant's term become 'blocked.' Sign information may come from C2 systems, text chat, telephones, or other operators. Operators may take an immediate action with a known response to a high priority input. Monitoring interprets the signs from the previous stage and generates symptoms as output. A situation produced by the signs or other operators may become blocked if the operator perceives the situation is a result of incorrect, uncorrelated, or obsolete information. Based on the priority of the signal, operators may decide to skip all intermediate steps and go directly to executing an immediate response or execute an ad hoc search for additional information. **Error! Reference source not found.** shows the most likely information flow pattern in monitoring activities.

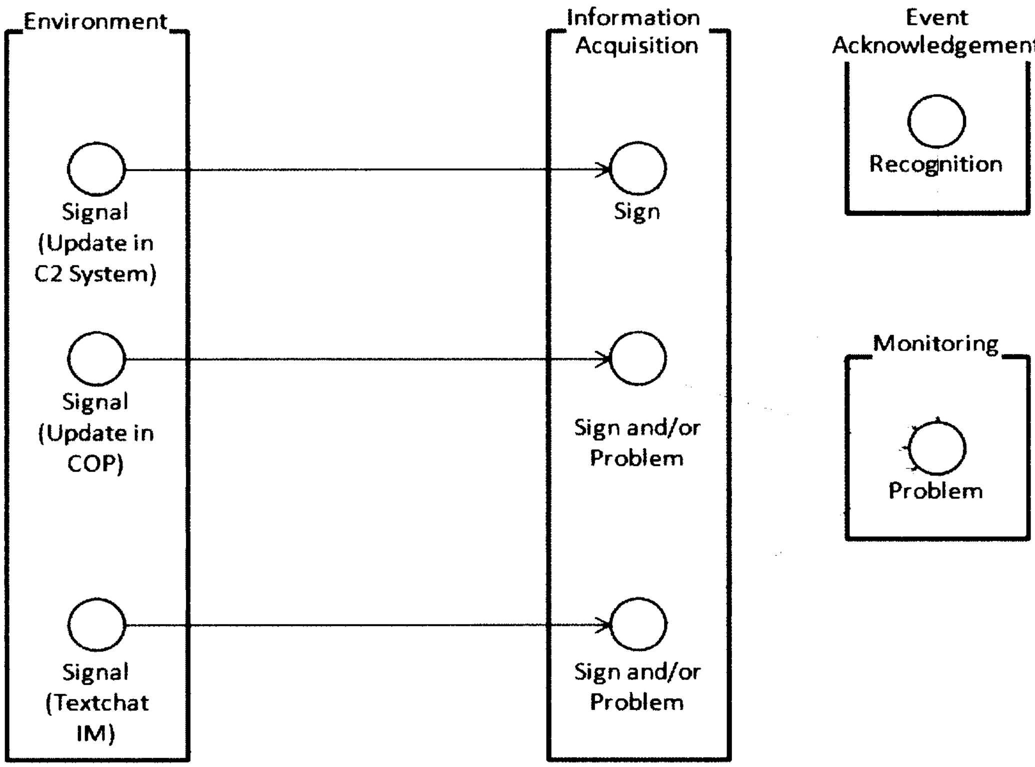



*Figure 24.* Monitoring

Redress occurs when monitoring and a perceived problem (perturbation) accrues. The members staffing Combat Operations try to determine location and/or cause of the anomalies, faults, or events that are receiving additional scrutiny. Individuals generate hypotheses based on synthesized information from multiple sources and senses. This stage continues diagnosis and starts cause analysis. Other operators start to bring to bear their expertise to validate reasoning if needed.

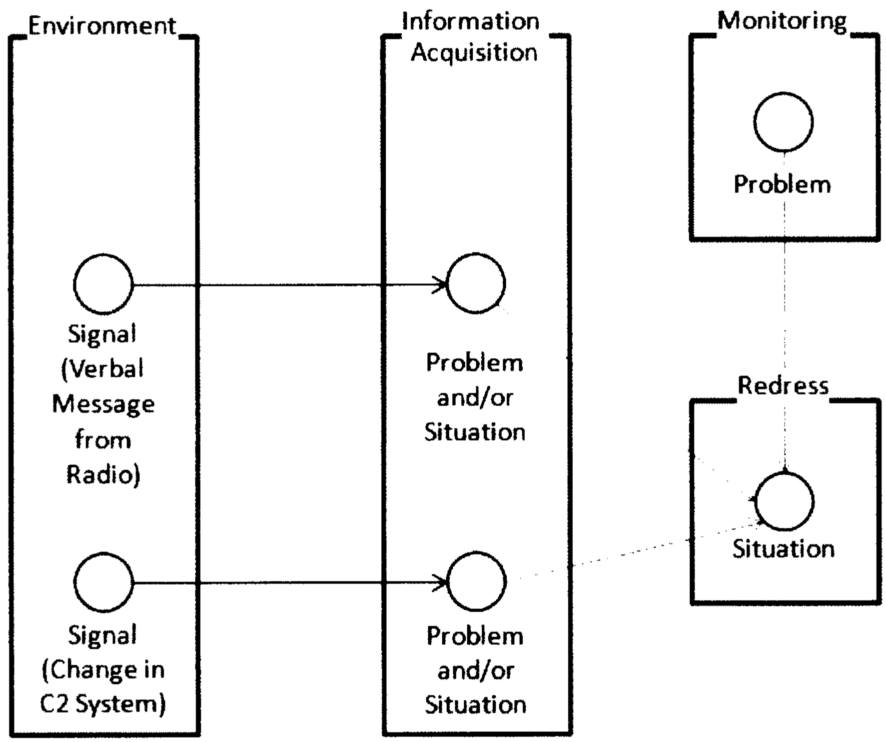



*Figure 25.* Redress

As redress happens, synchronizing will become a necessity. Floor operators will predict how to move back toward an expected outcome or how to minimize some losses. In synchronizing (coordinating), they will set goals, and procedures will start to become clear. Often, both goals and procedures will require some level of command decision. Procedures to respond to a situation are always formulated to achieve a goal. Procedures absolutely depend on the goal and involve the tasks expected to reach the goal. The goal may come from written guidance in documents like the ATO, Rules of Engagement (ROE), Air Operations Directive (AOD), or another source. The procedure could be written in the standard operating procedure (SOP), memorized through experienced and training, or given as oral instruction. The main impetus is to determine if something needs to be done and start implementation leading to execution.

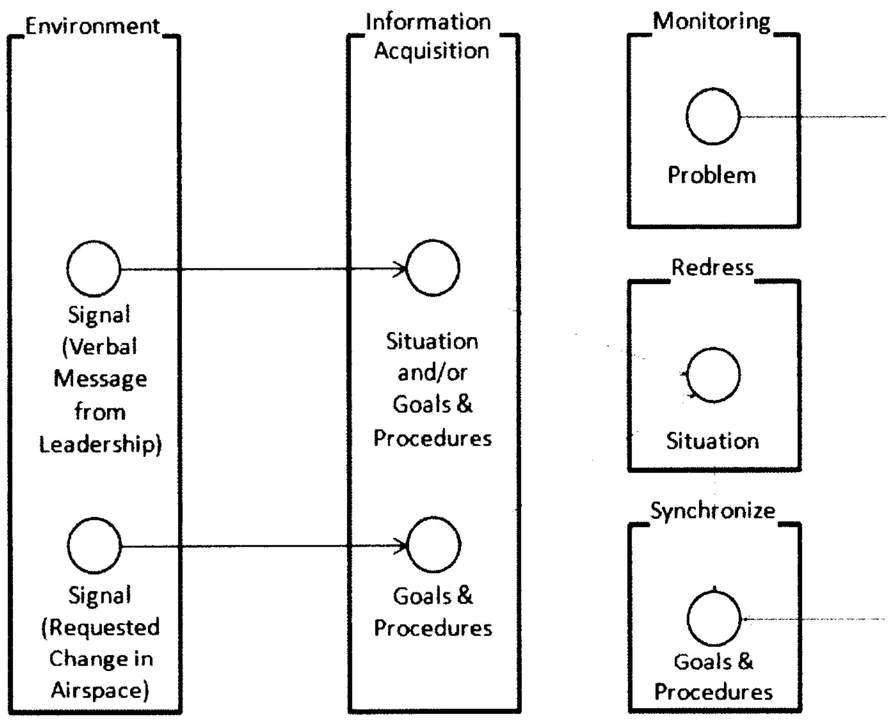



*Figure 26.* Coordination Process

If and when Implementation (**Error! Reference source not found.***27*) is accomplished, a schedule action will result as an output task accomplished using the MMI. The system output may be as simple as pushing the acquired information to another organization to resolve or scheduling some action to take later. Conversely, the task could be an immediate response requiring all available C2 systems and operators to come together to solve a task. An example of an immediate response would be executing a Time Sensitive Target (TST) mission.

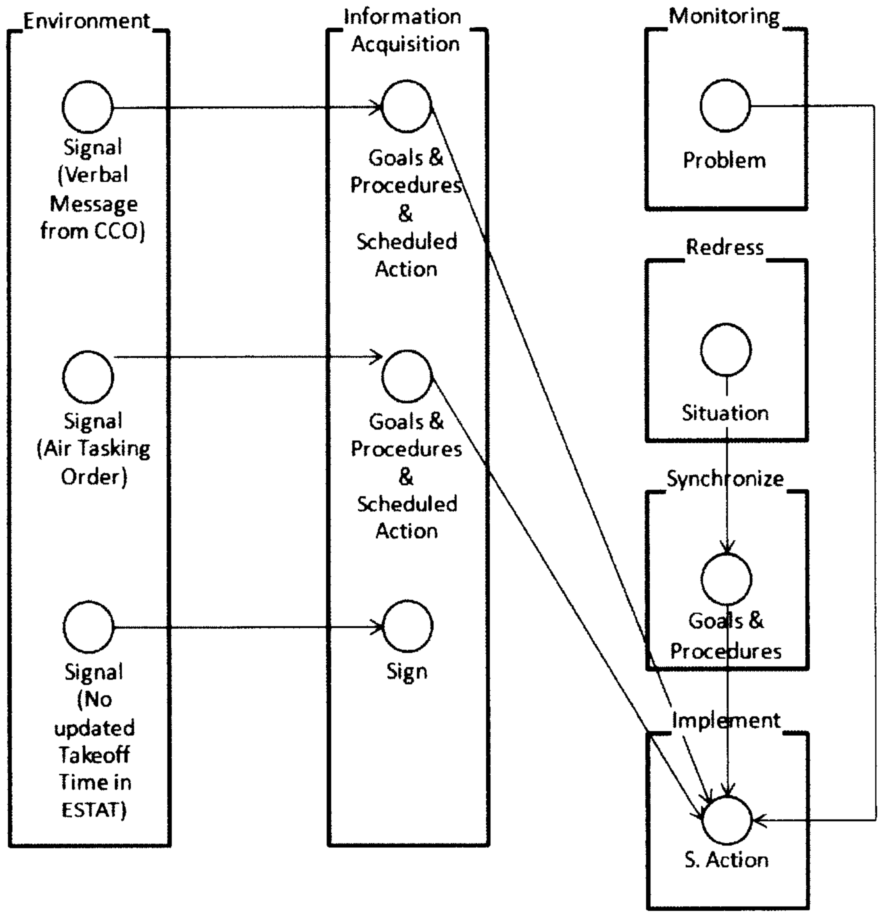



*Figure 27.* Implementation

Dynamic Targeting is any targeting inside the ATO cycle. It is a process that identifies emerging and/or fleeting targets and determines how they are prosecuted via kinetic or non-kinetic means. TSTs start with guidance, categorization, relative prioritization, assessment criteria, collection requirements, and many other aspects of prosecution. Most of the information builds or is determined in the pre-operation planning and/or as part of deliberate targeting. Often a TST decision matrix is created, but it is not a substitute for the warfighter fully understanding the underlying TST guidance, ROE, collateral damage methodologies, and TST operating procedures that form the TST decision matrix document. A good TST decision matrix framework should include TST prioritization, approval authority, restrictions, acceptable risk level, identification (ID) criteria, and desired effects. Operator guidance will be reviewed periodically to ensure it is appropriate and relevant as the nature of the threat and/or conflict changes. The result could be some sort of execution through the MMI as depicted in *Figure 28.*

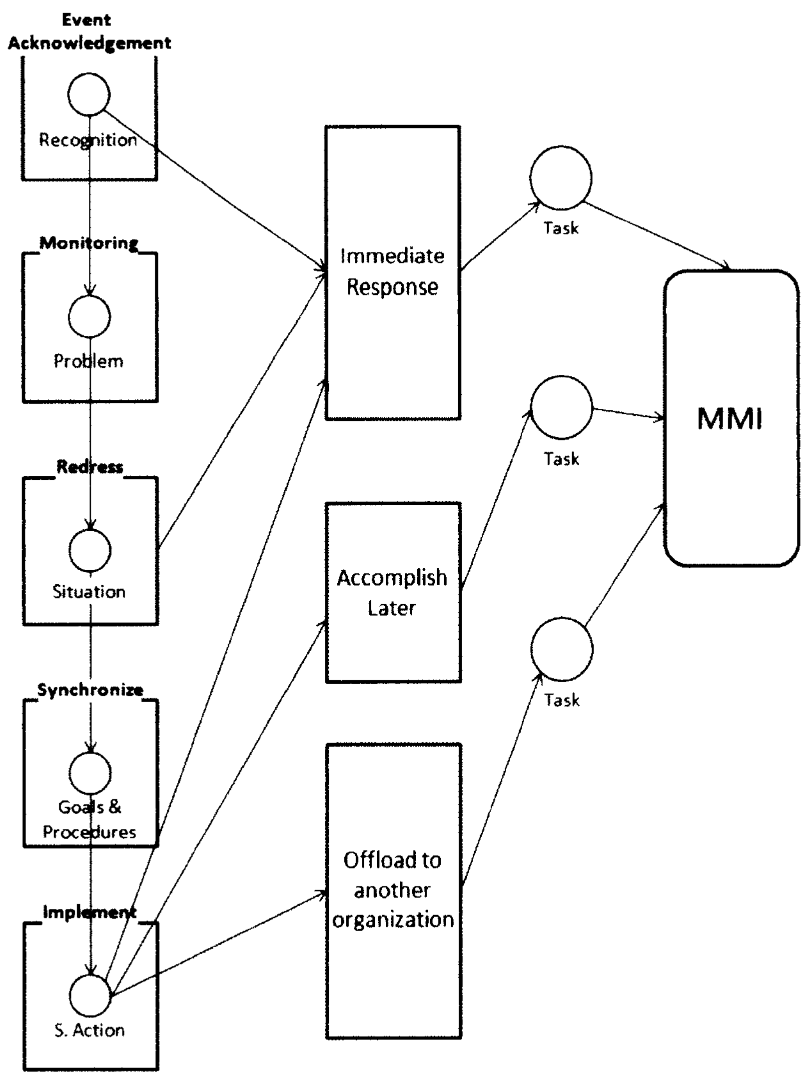



*Figure 28.* Execution

In the application of Conant's Model, total information flow is represented by the sum of the total rate for the subsystems. For convenience of calculation, assume the input from the environment has a probability approximately 'off' and 'on,' so each has 1 bit, though in a real situation probabilities about 'on' and 'off' are not equal, with 'off' being most likely. In the case of many-to-one mappings, assume output will be generated only if all input is 'on.' In information acquisition, there is no blockage, as all input is transferred to the Identification stage. Information blockage accrues when information does not transfer to the next stage because there is a reduction in the amount of information caused by many-to-one mappings. The goal is to fill in a chart similar to Table 5.

*Table 5.* Information Flow

| Term(Bit) Stages | Thru-put | Blockage | Coordination | Total Information Flow |
|---|---|---|---|---|
| Information Acquisition | | | | |
| Identification | | | | |
| Diagnosis | | | | |
| Total | | | | |

The information Flow 'F' is the amount of information processed by the individual operator or by the team as measured by Conant's method. It is also a measure of the uncertainty of the situation (Shannon, 1948). The amount can be represented as the sum of thru-put, blockage, and coordination (Ashby, 1948; Beer, 1985). Information processing in any task will be mapped (or integrated) as a set of input transforming into a set of output, thereby reducing uncertainty. The amount of process information directly relates to the operator's workload. If a task demands a load beyond the operator or team's ability, related errors may arise. Quantitative information analysis could level capacity or determine if a new or improved IT system provides value to the human network. By defining transformation of information in stages, I can quantify the proposed model. Each term (thru-put, blockage, and coordination) will be measured and considered as a workload that is designed to do the required tasks.

## 3.3 PHYSICAL MODEL MANIPULATION, DATA COLLECTION

To increase understanding of the output generated with the ELICIT model, it is critical to have positive control over the input. Positive control of dependent variables should allow understanding of independent variables operating in the ELICIT model. The selected case study method is a comparison. To evaluate the human network I will compare a nominal AOC organization structure to an AOC in an Edge organization construct. The dependent variable of the human network is represented by the abELICIT agents; the independent variables are the technical network infrastructure, which I manipulate.

In ELICIT, organizations are designed with the configuration file and agents, then process the factoids received to determine, among other things, whether to share that information with other agents it is connected to, or to post or pull factoids from a notional website dedicated to a particular aspect of the problem. For abELICIT, whether and when the agents have solved the problem is determined by processing the log files after the run is completed. Software agents may be parameterized according to 54 parameters that determine, among other aspects, the way they process information, build awareness, socialize and identify, whether to share, how often to share, and the propensity to seek information. These are all examples of agent parameters that can vary. A number of parameters are associated with the amount of time a particular action takes, e.g., how long it takes to share or post a factoid once the agent determines it will share or post. Finally, there are a few Boolean (on/off, true/false) parameters, such as whether the agent is a guesser or a hoarder of factoids.

Using this understanding of AbAgent based ELICIT, there are three primary data input mechanisms into the ELICIT C2 model that the experimenter can control: 1) the configuration file; the 2) factoid list; and 3) what actions are available. For this comparison case study, actions available are held constant in both the Nominal and Edge AOC organization

### 3.3.1 Configuration File

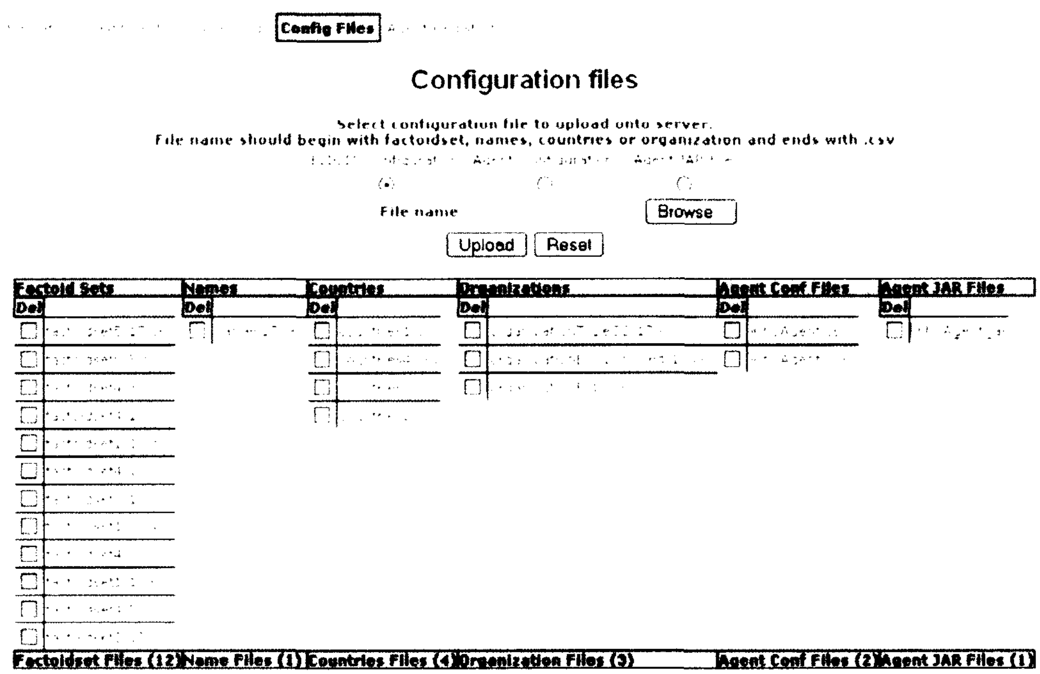



*Figure 29.* ELICIT Configuration Screen

Figure 29 shows how an organization type .csv file can be loaded into the ELICIT server. Support from an information technology specialist is not required.

The file is in .csv (comma-delimited) format, which means that the value in each field is separated with a comma or similar marker. In the ELICIT configuration files, the fields are separated with a vertical bar (|).

A key at the top of the ELICIT configuration example file explains data within:

n|Role|team|Country|1|2|3|...17|Web site1| Web site2| Web site3| Web site4

beginning on line 5 with the player number, a team member identity, and a country label for that player (if a code of <country*> is supplied, then the $n^{th}$ entry in the country table specified for the experiment trial is used). The table is completed with a series of numeral 1's with a single 0, which is sequentially arrayed across the grid. If there is a 1 in the first player position, then the player associated with the row can share with the first player. If there is a 0 in the 5th player position, then the player associated with the row cannot share with the 5th player. In a traditional ELICIT construction, if there is a 1 in a Web site column, then the player associated with that row can access the Web site. If there is a 0 in a Web site column, then the player associated with that row cannot access the Web site. For this case study ELICIT has been modified to allow read (R), write (1), and no access (0) to the various Web pages. In the following example, the organization file is the ELICIT baseline C2-17.csv (the 17-playerconfiguration file for a C2 organization). In this organization type, the Cross-Team Coordinator and four Team Leaders (who coordinate who, what, when, and where information), have different access privileges to the Web sites. The Cross-Team Coordinator can access all four Web sites. The remaining

16 players each can access only one Web site. Line 22 assigns these players to group B, the C2 organization. The final lines list the names of the Web sites.

*Table 6.* Original ELICIT Configuration

```
Original ELICIT Configuration

n|Role|Team|Country            |1|2|3|4|5|6|7|8|9|10|11|12|13|14|15|16|17|website1|website2|website3|website4|
1|Cross Team Coordinator      |0|1|1|1|1|1|1|1|1|1 |1 |1 |1 |1 |1 |1 |1 |1 |1 |1 |
2|Team leader|Who|<country1>  |1|0|1|1|1|1|1|1|1|1 |1 |1 |1 |1 |1 |1 |1 |0 |0 |0 |
3|Team leader|what|<country2> |1|1|0|1|1|1|1|1|1|1 |1 |1 |1 |1 |1 |1 |0 |1 |0 |0 |
4|Team leader|where|<country3> |1|1|1|0|1|1|1|1|1|1 |1 |1 |1 |1 |1 |1 |0 |0 |1 |0 |
5|Team leader|when|<country4  |1|1|1|1|0|1|1|1|1|1 |1 |1 |1 |1 |1 |1 |0 |0 |0 |1 |
6|Team member|Who|<country1>  |1|1|1|1|1|0|1|1|1|1 |1 |1 |1 |1 |1 |1 |1 |0 |0 |0 |
7|Team member|Who|<country1>  |1|1|1|1|1|1|0|1|1|1 |1 |1 |1 |1 |1 |1 |1 |0 |0 |0 |
8|Team member|who|<country1>  |1|1|1|1|1|1|1|0|1|1 |1 |1 |1 |1 |1 |1 |1 |0 |0 |0 |
9|Team member|what|<country2> |1|1|1|1|1|1|1|1|0|1 |1 |1 |1 |1 |1 |1 |0 |1 |0 |0 |
10|Team member|what|<country2> |1|1|1|1|1|1|1|1|1|0 |1 |1 |1 |1 |1 |1 |0 |1 |0 |0 |
```

```
11|Team member|what|<country2>   |1|1|1|1|1|1|1|1|1|1  |0  |1  |1  |1  |1  |1  |1  |0     |1     |0     |0     |
12|Team member|where|<country3>  |1|1|1|1|1|1|1|1|1|1  |1  |0  |1  |1  |1  |1  |1  |0     |0     |1     |0     |
13|Team member|where|<country3>  |1|1|1|1|1|1|1|1|1|1  |1  |1  |0  |1  |1  |1  |1  |0     |0     |1     |0     |
14|Team member|where|<country3>  |1|1|1|1|1|1|1|1|1|1  |1  |1  |1  |0  |1  |1  |1  |0     |0     |1     |0     |
15|Team member|when|<country4>   |1|1|1|1|1|1|1|1|1|1  |1  |1  |1  |1  |0  |1  |1  |0     |0     |0     |1     |
16|Team member|when|<ountry4>    |1|1|1|1|1|1|1|1|1|1  |1  |1  |1  |1  |1  |0  |1  |0     |0     |0     |1     |
17|Team member|when|<country4>   |1|1|1|1|1|1|1|1|1|1  |1  |1  |1  |1  |1  |1  |0  |0     |0     |0     |1     |
```

For the case study, I will create manipulation system fragmentation by increasing the number of websites in a stepwise manner.

The following will be the configuration file headers for the case study. The corresponding table and .csv files will be created at the execution of the case study.

How to read tables:

*Table 7*. Initial Configuration

<table>
<tr><td>Initial Configuration</td></tr>
<tr><td>n|Role|Team|Country|1|2|3|4|5|6|7|8|9|10|11|12|13|14|15|16|17|18|19|20|21|22|23|24|</td></tr>
<tr><td>Continuation of n|</td></tr>
<tr><td>25|26|27|28|website1|website2|website3|website4|website5|website6|website7|website8|website9|website10|</td></tr>
</table>

The configuration Table will be modified to increase system fragmentation in a 3-step process.

First .csv file header row was as follows:

*Table 8*. First Increment of Fragmentation Configuration

<table>
<tr><td>First Increment of Fragmentation Configuration</td></tr>
<tr><td>n|Role|Team|Country|1|2|3|4|5|6|7|8|9|10|11|12|13|14|15|16|17|18|19|20|21|22|23|24|</td></tr>
<tr><td>Continuation of n|</td></tr>
<tr><td>25|26|27|28|JFCwebsite1|JFACCwebsite1|CRCwebsite1|WOCwebsite1|ASOCWebsite1|CORPwebsite1|SOCwebsite1|</td></tr>
</table>

Continuation of n|

Fleetwebsite1|TACCwebsite1|C-CPwebsite1|

Second header row was as follows:

*Table 9.* Second Increment of Additional Fragmentation Configuration

Second Increment of Additional Fragmentation Configuration

n|Role|Team|Country|1|2|3|4|5|6|7|8|9|10|11|12|13|14|15|16|17|18|19|20|21|22|23|24|

Continuation of n|

25|26|27|28|JFCwebsite1|JFCwebsite2|JFACCwebsite1|JFACCwebsite2|CRCwebsite1|CRCwebsite2|WOCwebsite1|

Continuation of n|

WOCwebsite2|ASOCWebsite1|ASOCWebsite2|CORPwebsite1|CORPwebsite2|SOCwebsite1| SOCwebsite2|Fleetwebsite1|

Continuation of n|

Fleetwebsite2|TACCwebsite1| TACCwebsite2|C-CPwebsite1| C-CPwebsite2|

Third header row was as follows:

*Table 10.* Third Increment of Additional Fragmentation Configuration

<table>
<tr><th>Third Increment of Additional Fragmentation Configuration</th></tr>
<tr><td>n|Role|Team|Country|1|2|3|4|5|6|7|8|9|10|11|12|13|14|15|16|17|18|19|20|21|22|23|24|</td></tr>
<tr><td>Continuation of n|</td></tr>
<tr><td>25|26|27|28|JFCwebsite1|JFCwebsite2|JFCwebsite3|JFACCwebsite1|JFACCwebsite2|JFACCwebsite3|CRCwebsite1|</td></tr>
<tr><td>Continuation of n|</td></tr>
<tr><td>CRCwebsite2|CRCwebsite3|WOCwebsite1|WOCwebsite2|WOCwebsite3|ASOCWebsite1|ASOCWebsite2|ASOCWebsite3|</td></tr>
<tr><td>Continuation of n|</td></tr>
<tr><td>CORPwebsite1|CORPwebsite2|CORPwebsite3|SOCwebsite1| SOCwebsite2| SOCwebsite3|Fleetwebsite1| Fleetwebsite2|</td></tr>
<tr><td>Continuation of n|</td></tr>
<tr><td>Fleetwebsite3|TACCwebsite1| TACCwebsite2| TACCwebsite3|C-CPwebsite1| C-CPwebsite2| C-CPwebsite3|</td></tr>
</table>

### 3.3.2 Factoid File

By evolving the ELICIT software platform, tools, and procedures, I am able to support conducting ELICIT experiments using operations tasks. I started with the baseline ELICIT task (Ruddy, 2007), which is an intelligence task. Periodically during an experiment, ELICIT distributes *factoids* (i.e., information elements that are pieces of the scenario) to the participants. Participants can choose to disseminate or not disseminate factoids to others by sharing information directly with a particular participant or by posting a factoid to a particular information system. However, only by communicating information can participants achieve sufficient levels of awareness to complete the task. The four original baseline factoid sets each contain 68 factoids (four for each of the 17 participants). These factoids contain only true information. There is no incorrect or conflicting information. Each factoid belongs to one of four categories:

1) Key (K) - Contains information that is essential for a specific problem space.
2) Expertise (E) - Contains information that is essential for solving the problem and may be important for more than one specific aspect of the task space, such as special information a team leader may possess.
3) Supportive (S) - Contains information which supports key and expertise factoids
4) Noise (N) – Contains information that is irrelevant to solving the task.

Each baseline *Factoid Set* consists of 17 Key or Expertise, 17 Supportive and 34 Noise factoids. Thus, the ratio of relevant information to noise is 50%.

For purposes of the original experiment design, I took care to treat each participant equally. The factoid scenarios are anonymized to reduce distractions based on previous experiences.

In this Air Power case study, I started out with 50% noise. For the second run, I added two more noise factoids per participant, bringing the noise percentage up to 66%. For the final run, there are six noise factoids, bringing the noise percentage up to 75%. Although I did not increase noise enough to choke the system, by choosing these three steps, I was able to discern any trends. The experiment design is to measure the time needed to arrive at shared awareness across two different organizational structures (Nominal, Edge) when step increasing two different information flow variables (noise, system fragmentation). An increasing number of websites represents system fragmentation, and increasing the number of noise factoids represents noise. At one time, I planned to accomplish system fragmentation by breaking Key and Supporting factoids into multiple inputs. The technique of breaking Key and Supporting factoids into multiple inputs failed in execution, as there was no way to determine if resulting system perturbations merely reflected a change in syntaxes and not system fragmentation.

## 3.4 DATA CAPTURE

The variables expected to be measured by data extracted from the ELICIT *datalogs* are presented below.

*Table 11.* Variables

| Category | Variable | Description |
|---|---|---|
| Social | Interactions Activity | Average number of interactions (i.e., total shares, posts and pulls) per subject. |
| | Average Network Reach | Network reach measures the percentage of subjects that a specific subject interacted with. The average network reach is the average value across all organizations and is measured here as a percentage. |
| Information | Interactions Activity | Average number of interactions (i.e., total shares, posts and pulls) per subject. |
| | Relevant Information Reached (average and per key role) | Relevant conclusion reached: - average amount and percentage across both organizations - amount per key role (JFC, JFACC, CCO) |
| | Shared Relevant Information | Amount of relevant factoids accessible by all subjects. Measured as number and percentage of factoids. |
| Measure of Merit | (Mission) Effectiveness | Measures the degree of effectiveness of the organization, based on the C2 approach (Nominal, Edge) |
| | (Mission) Time Efficiency | Measures the efficiency of the organization when using time as indication of cost. |
| | (Mission) Effort Efficiency | Measures the efficiency of the organization when using effort as indication of cost. |
| | Maximum Timeliness | *The time to first correct and complete identification by any participant relative to the time available* (Alberts, 2011). |

## 3.5 DATA ANALYSIS

The data measurements expected from the ELICIT datalogs are as follows:

### 3.5.1 General Measurements

*Table 12.* General Measurements

| Name | Value Type | Description |
|---|---|---|
| Duration | Number | Duration of a run (in agent's time, measured in Minutes) |
| Compression factor | Number | Compression of time used to accelerate agent runs (e.g., 0.1 means 1 minute in agent's time is 10 minutes in human's time)<br><br>This input variable will be recorded and changed if required. |
| Total Shares | Number | Number of shares performed by all members |
| Total Posts | Number | Number of posts performed by all members |
| Total Pulls | Number | Number of pulls performed by all members |
| Total IDs | Number | Number of IDs performed by all members |
| List of Sense Making agent files | Text | Filename of agents file configuration |
| Workload | Number | Measured as the number of actions requiring information processing work; that is, number of share received actions, pull actions, and direct distributions |

### 3.5.2 Social Measurements

*Table 13.* Social Measurements

| Name | Value Type | Description |
|---|---|---|
| Interactions activity (mean value) | Number | Mean value of interaction activities (i.e., number of shared, posts and pulls) per subject. |
| Team inward-outward ratio | Number [0..1] | The ratio of inter and intra team interactions (i.e., shares) divided by total number of interactions. |

### 3.5.3 Informational Measurements

*Table 14.* Informational Measurements

| Name | Value Type | Description |
|---|---|---|
| Relevant facts accessible | [0..#KES factoids] | Number of K/E/S factoids accessible to organization |
| Facts accessible (number of) | [0..#factoids] | Number of factoids accessible to organization |
| Quality of ID 50% through event by CCO | [0…100%] | Quality of Interactions, Self-Synchronization, Mission Effectiveness and Mission Efficiency (given Effectiveness) (Manso & Nunes, 2007; McEver, Hayes & Martin, 2007; Martin & McEver, 2008). |
| Quality of ID at the end of the event by CCO | [0…100%] | Quality of Interactions, Self-Synchronization, Mission Effectiveness and Mission Efficiency (given Effectiveness) (Manso & Nunes, 2007; McEver, Hayes & Martin, 2007; Martin & McEver, 2008).. |
| Quality of ID 50% through event by JFACC | [0…100%] | Quality of Interactions, Self-Synchronization, Mission Effectiveness and Mission Efficiency (given Effectiveness) (Manso & Nunes, 2007; McEver, Hayes & Martin, 2007; Martin & McEver, 2008). |
| Quality of ID at the end of the event by JFACC | [0…100%] | Quality of Interactions, Self-Synchronization, Mission Effectiveness and Mission Efficiency (given Effectiveness) (Manso & Nunes, 2007; McEver, Hayes & Martin, 2007; Martin & McEver, 2008).. |
| Quality of ID 50% through event by JFC | [0…100%] | Quality of Interactions, Self-Synchronization, Mission Effectiveness and Mission Efficiency (given Effectiveness) (Manso & Nunes, 2007; McEver, Hayes & Martin, 2007; Martin & McEver, 2008). |
| Quality of ID at the end of the event by JFACC | [0…100%] | Quality of Interactions, Self-Synchronization, Mission Effectiveness and Mission Efficiency (given Effectiveness) (Manso & Nunes, 2007; McEver, Hayes & Martin, 2007; Martin & McEver, 2008). |

### 3.5.4 Shared Awareness Critical Measurements

*Table 15.* Shared Awareness Critical Measurements

| Name | Value Type | Description |
|---|---|---|
| Number of Partially Correct IDs | [0..4 * nbrSubjects | Number of partially correct identifications provided by subjects |
| Time of First Correct ID | Number | The time to first correct and complete identification by any participant |
| CSSync (Cognitive Self-Synchronization) | Number [0..1] | Cognitive self-synchronization value (Marco & Moffat, 2011) |
| CSSync Uncertainty | Number [0..1] | Uncertainty measurement associated with CSSync (Marco & Moffat, 2011) |

These quantitative numbers will be during 18 different model runs as defined in the following table:

*Table 16.* Nominal C2 and Edge C2 Runs

| Nominal C2 | Edge C2 |
|---|---|
| 1X System Fragmentation | 1X System Fragmentation |
| 2X System Fragmentation | 2X System Fragmentation |
| 3X System Fragmentation | 3X System Fragmentation |
| No Noise | No Noise |
| 50% Noise | 50% Noise |
| 66% Noise | 66% Noise |
| 75% Noise | 75% Noise |
| 1X System Fragmentation + 50% Noise (Best Case) | 1X System Fragmentation + 50% Noise (Best Case) |
| 3X System Fragmentation + 75% Noise (Worst Case) | 3X System Fragmentation + 75% Noise (Worst Case) |

As this is a comparison case study, I will compare the nominal AOC to the Edge AOC for trends and deviations. The baseline for both types of AOCs will be 1X System Fragmentation and/or 50% noise.

### 3.5.5 1X System Fragmentation Edge as compared to Nominal

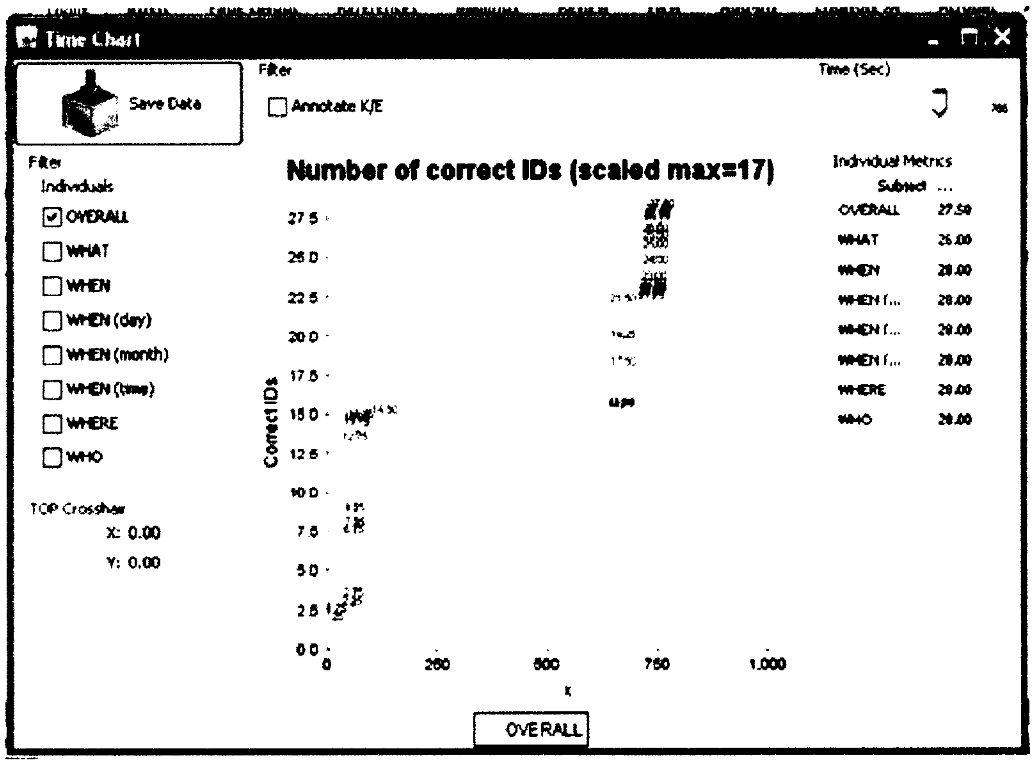



*Figure 30.* 1X System Fragmentation Number of Correct IDs, Edge

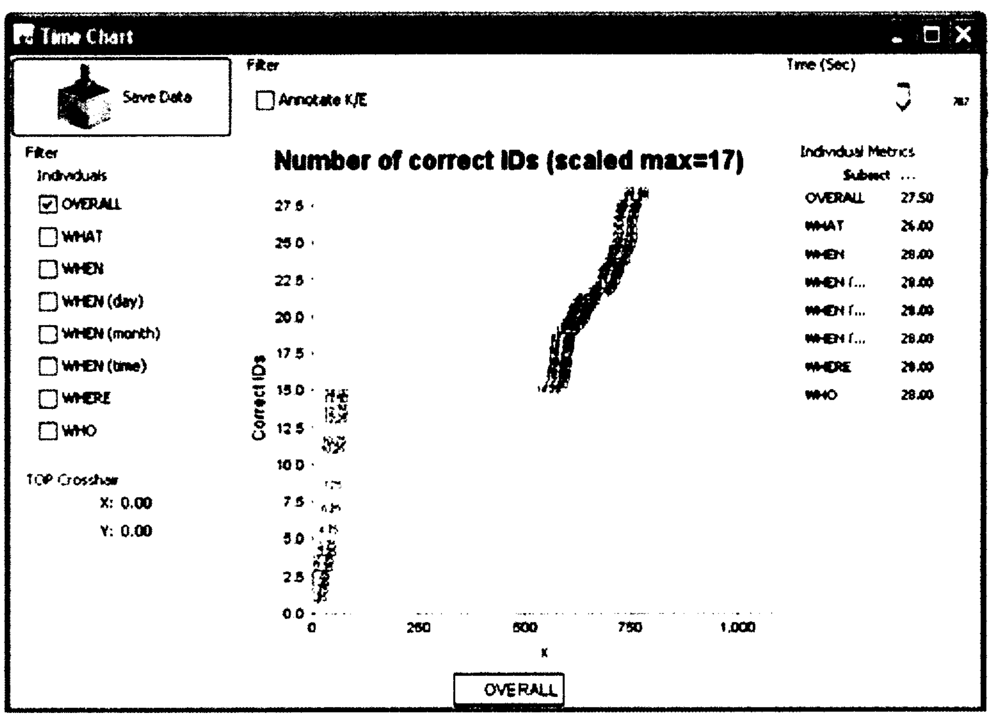



*Figure 31.* 1X System Fragmentation Number of Correct IDs, Nominal

Edge and Nominal organizations both find the final solution but a nominal construct tends for more individuals to determine what the 'moving' solution is earlier.

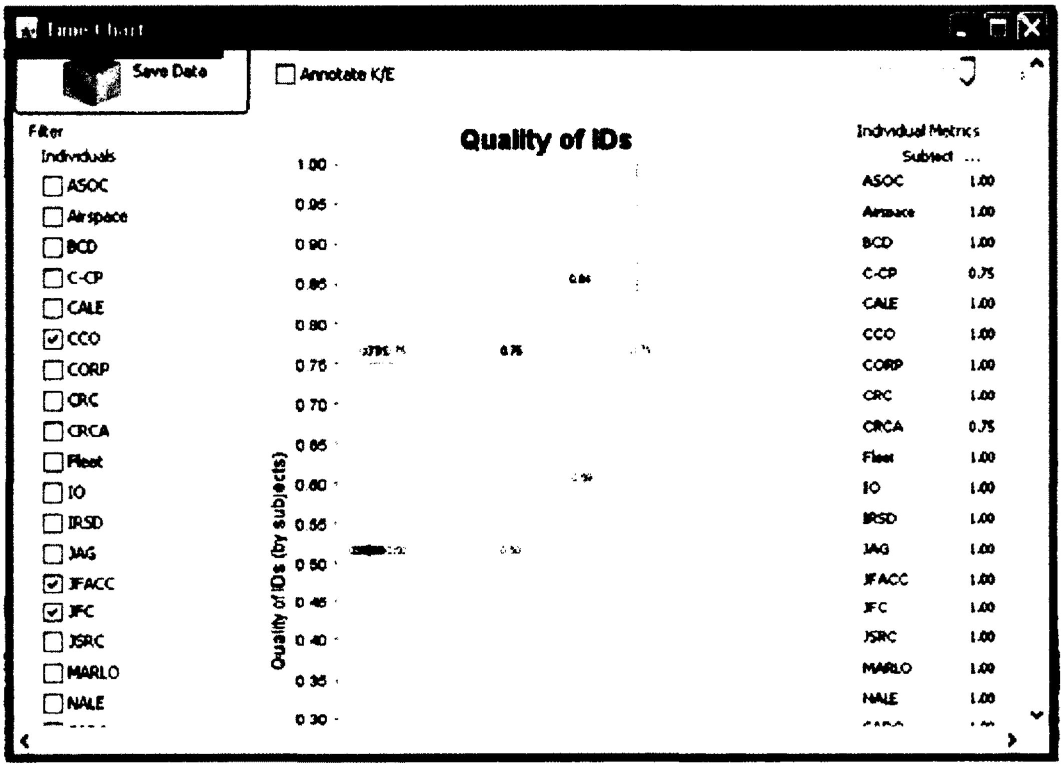



*Figure 32.* 1X System Fragmentation Quality of IDs, Edge

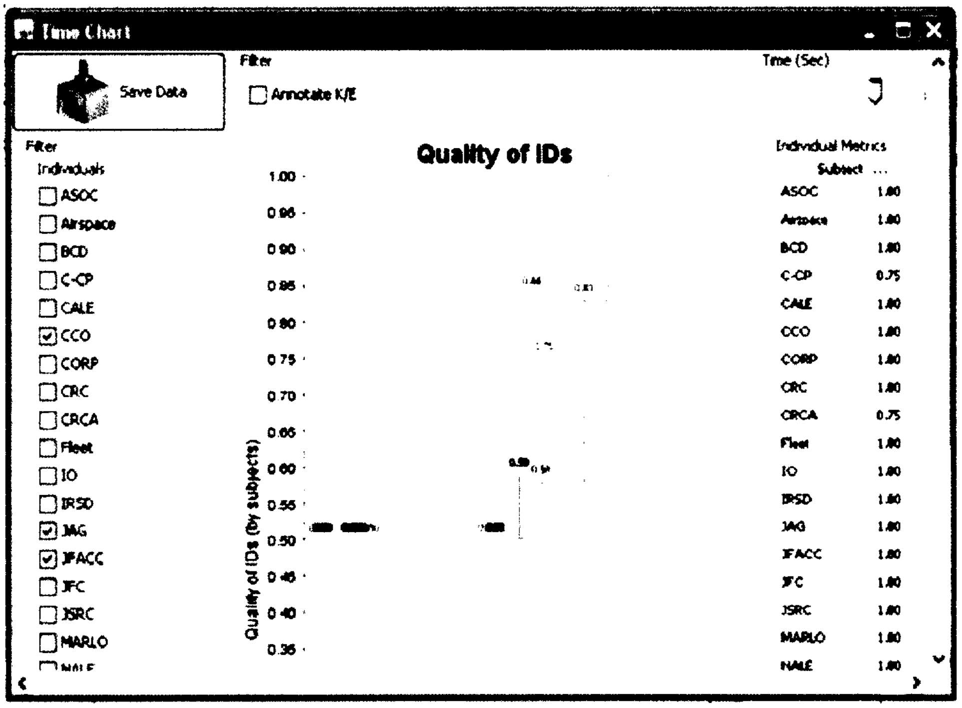



*Figure 33.* 1X System Fragmentation Quality of IDs, Nominal

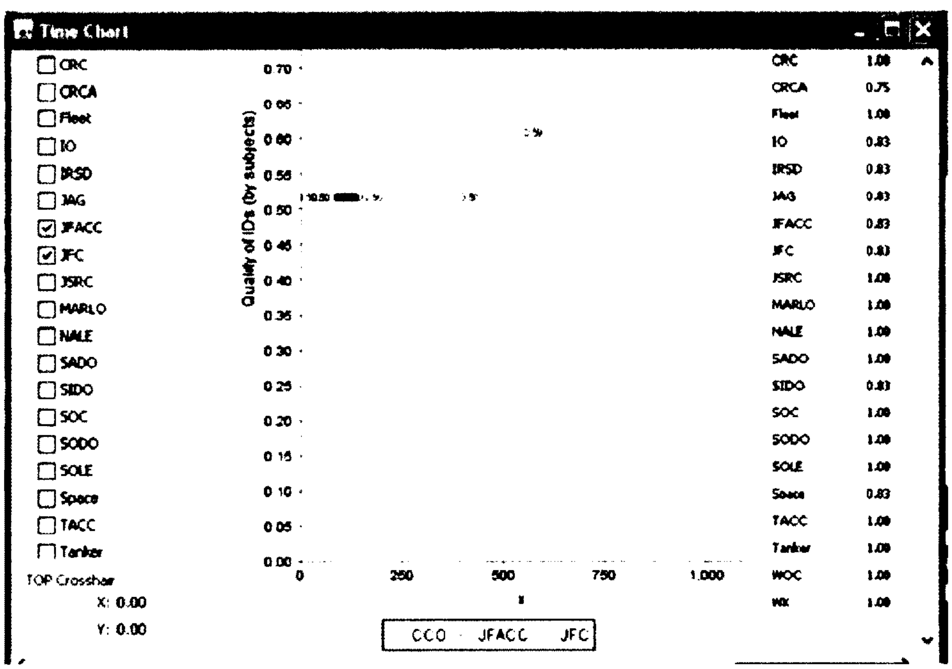



*Figure 34.* Color definitions

Using Quality of ID as a yardstick, the Edge organization tends for some individuals to have better understanding early, but the nominal organization tends to have closer group understanding.

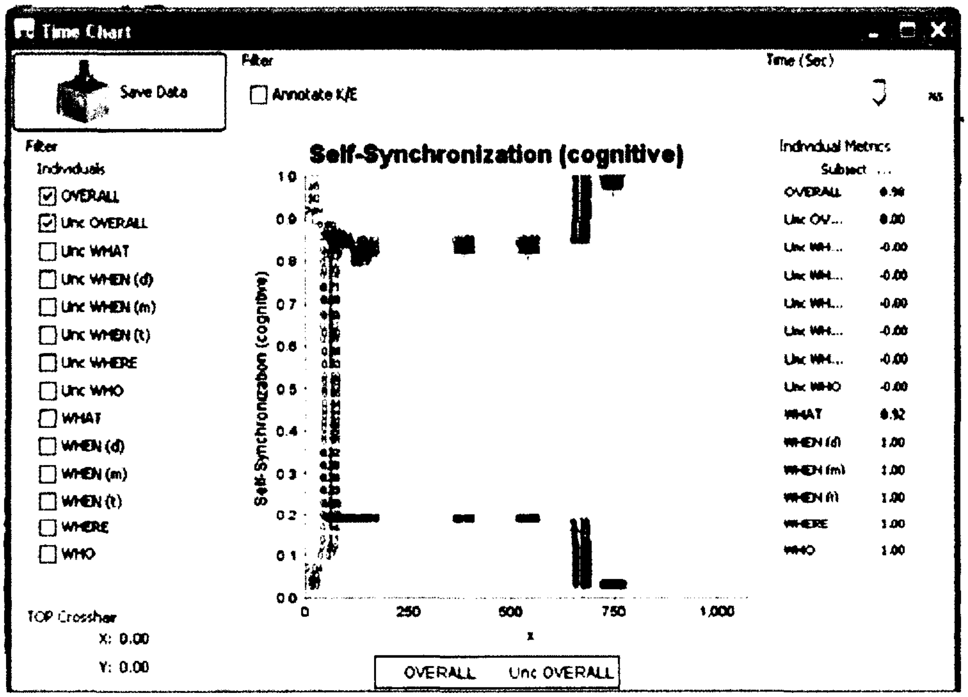



*Figure 35.* 1X Self-Synchronization, Edge

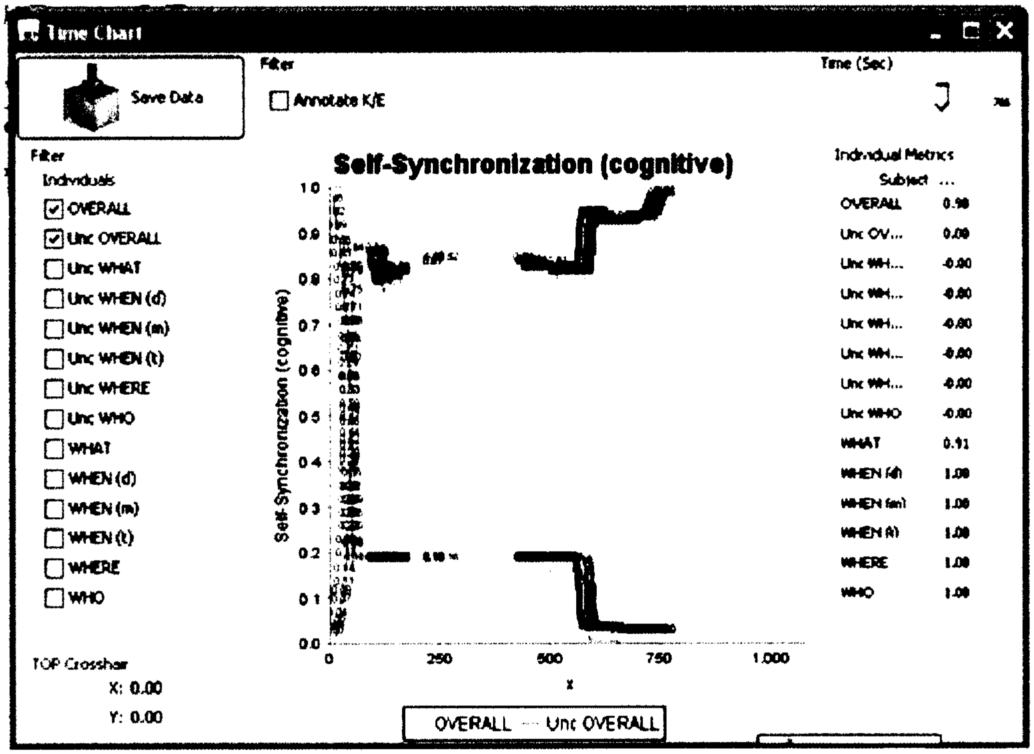



*Figure 36.* 1X Self-Synchronization, Nominal

When I look at the Self-Synchronization (cognitive) charts, the Edge organization synchs early and late, with the Nominal organization bringing more along earlier.

### 3.5.6 2X System Fragmentation Edge as compared to Nominal

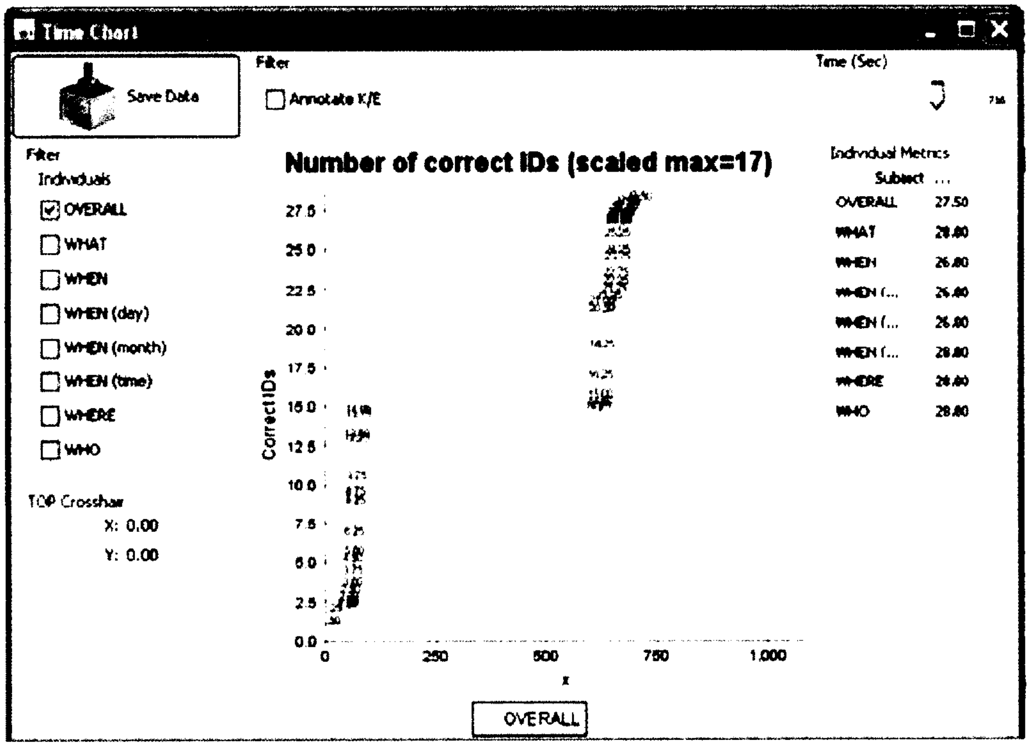



*Figure 37.* 2X System Fragmentation Number of IDs, Edge

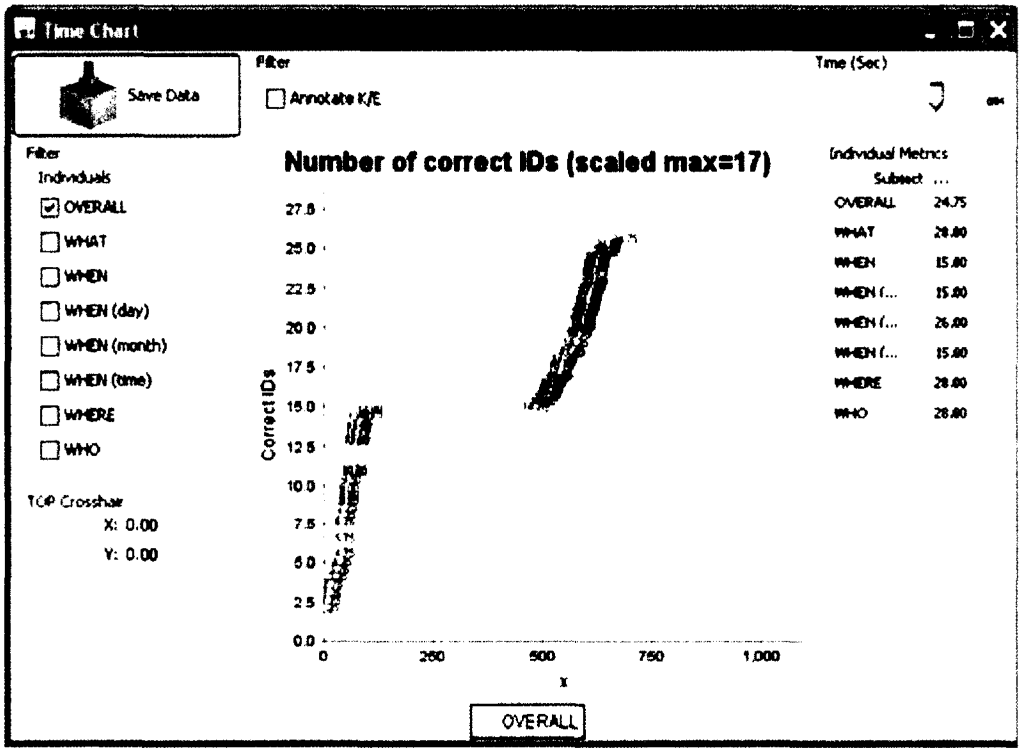



*Figure 38.* 2X System Fragmentation Number of Correct IDs, Nominal

As System Fragmentation increases, I see the same pattern as the Nominal organization tends to bring all along in understanding earlier.

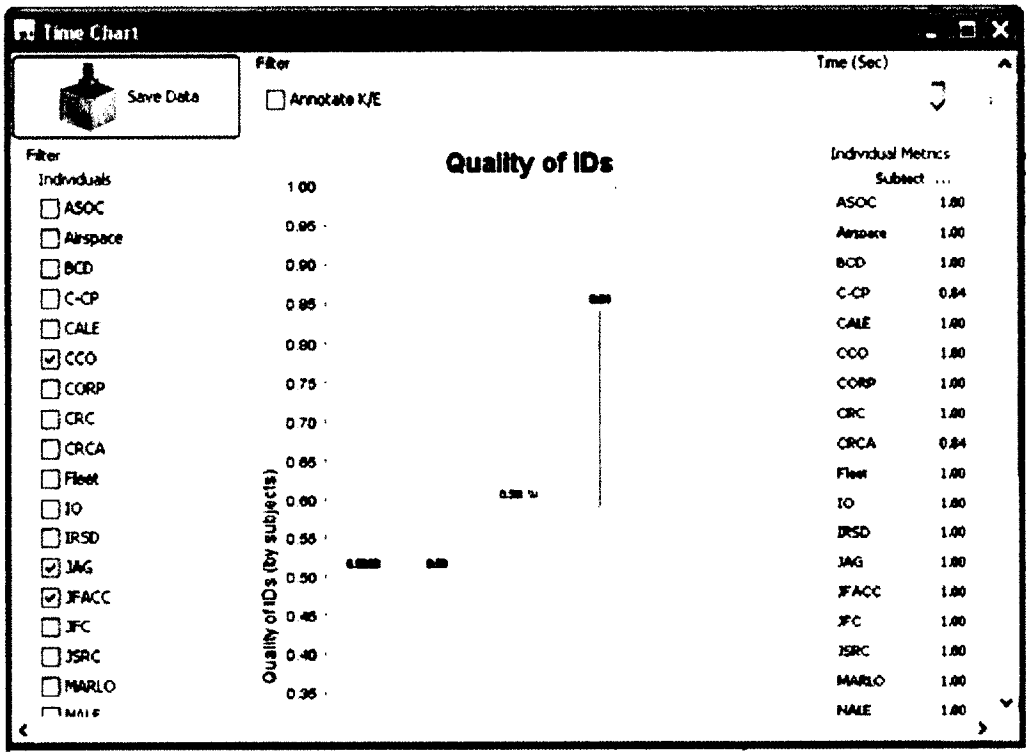



*Figure 39.* 2X System Fragmentation Quality of IDs, Edge

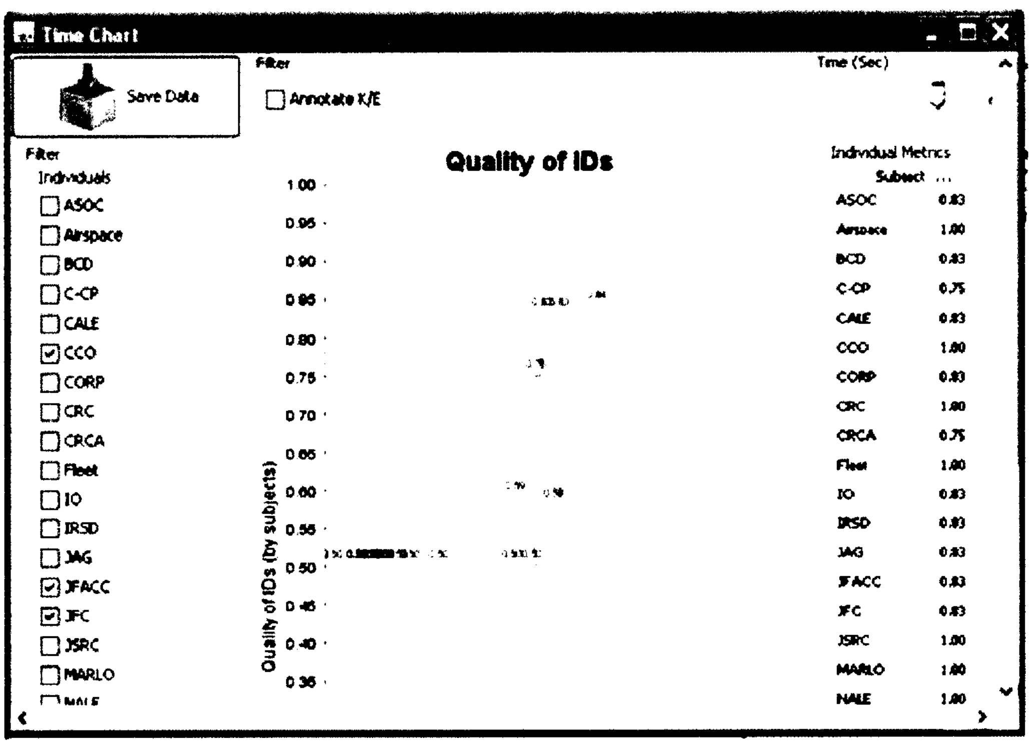



*Figure 40.* 2X System Fragmentation Quality of IDs, Nominal

As system fragmentation rate doubles, not all are even able to complete understanding in the nominal organization.

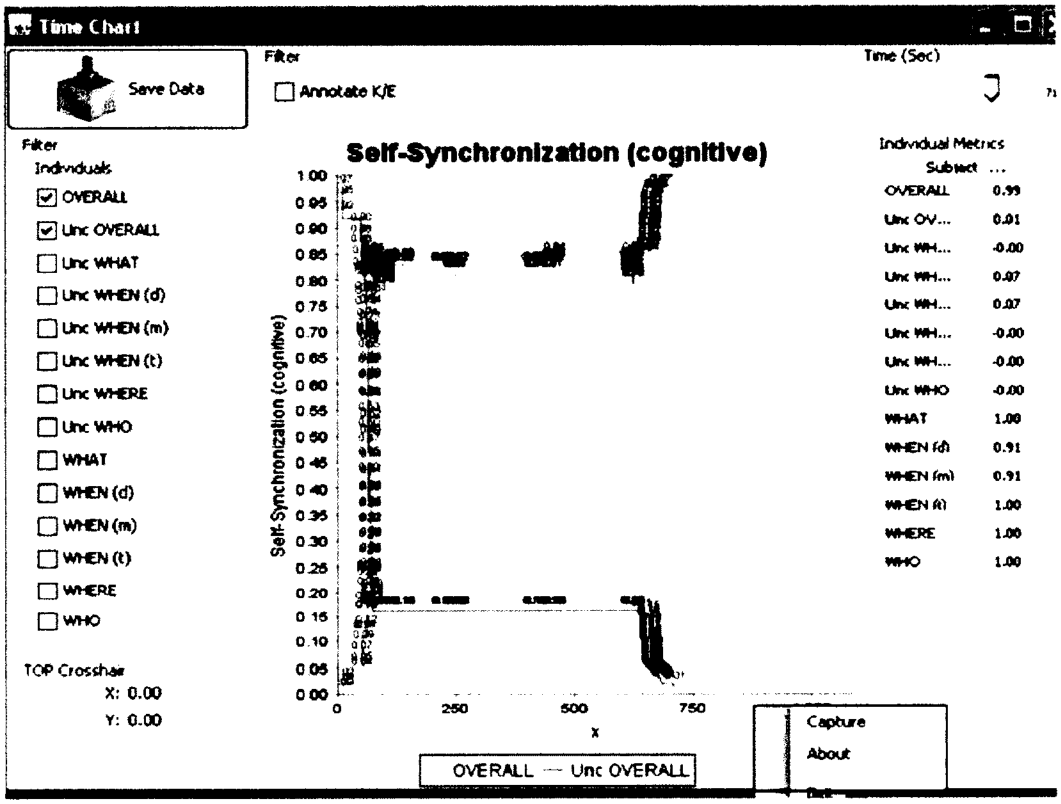



*Figure 41.* 2X Self-Synchronization, Edge

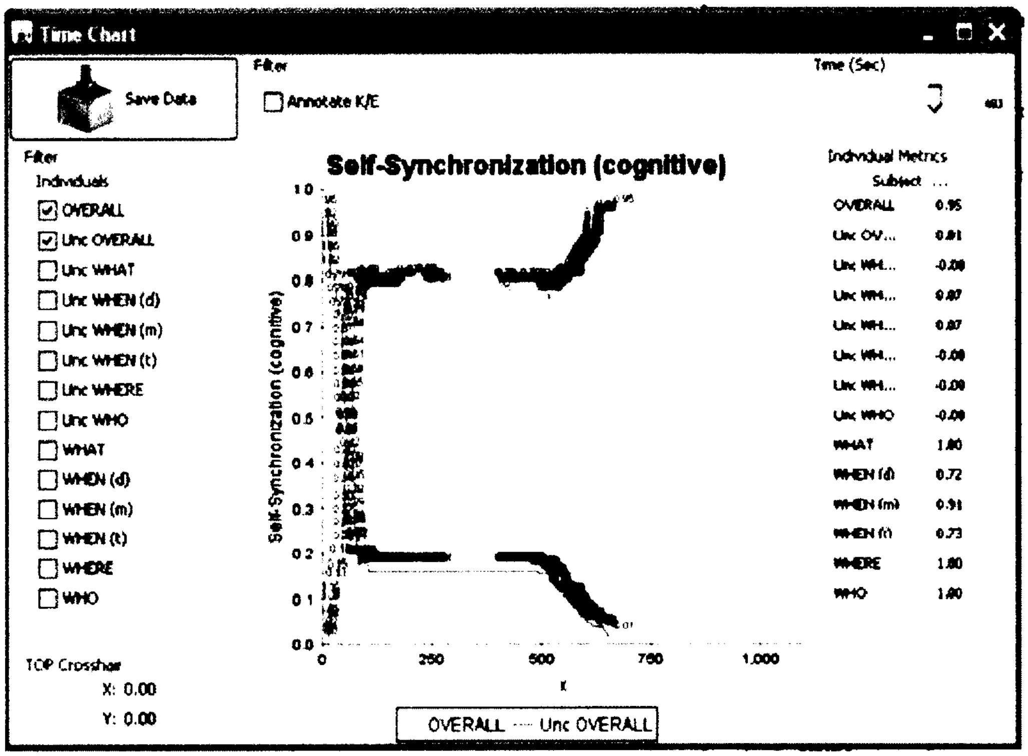



*Figure 42.* 2X Self-Synchronization, Nominal

With double fragmentation the pattern of more people Self-Synchronization earlier when compared with the Nominal organization

### 3.5.7 3X System Fragmentation Edge as Compared to Nominal

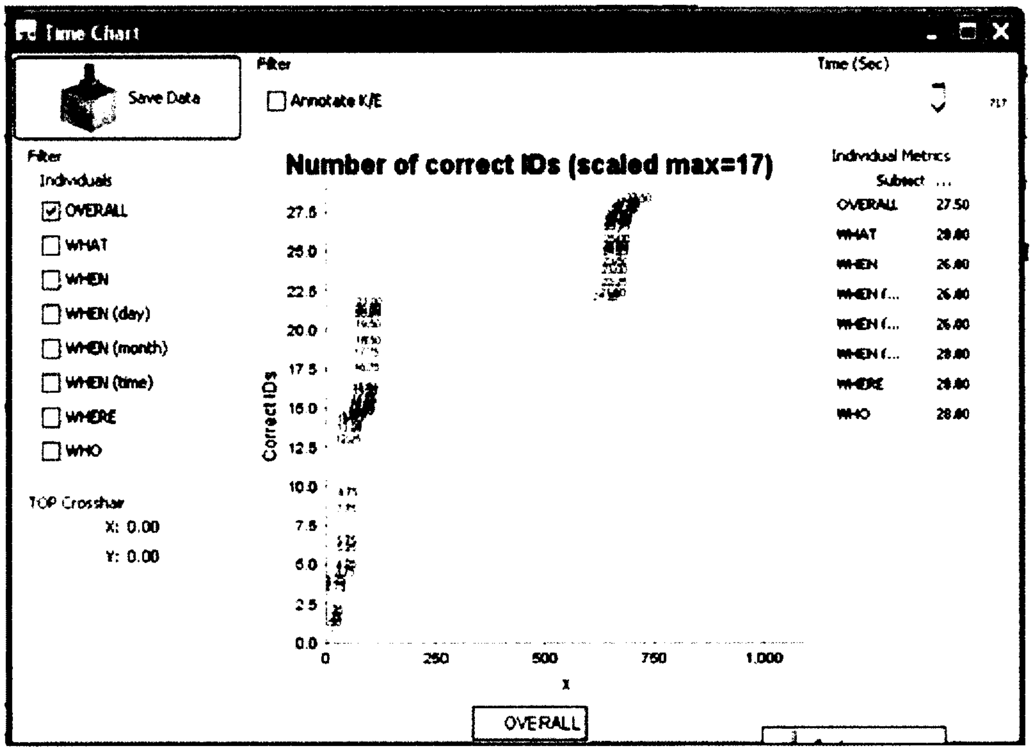



*Figure 43.* 3X System Fragmentation Number of IDs, Edge

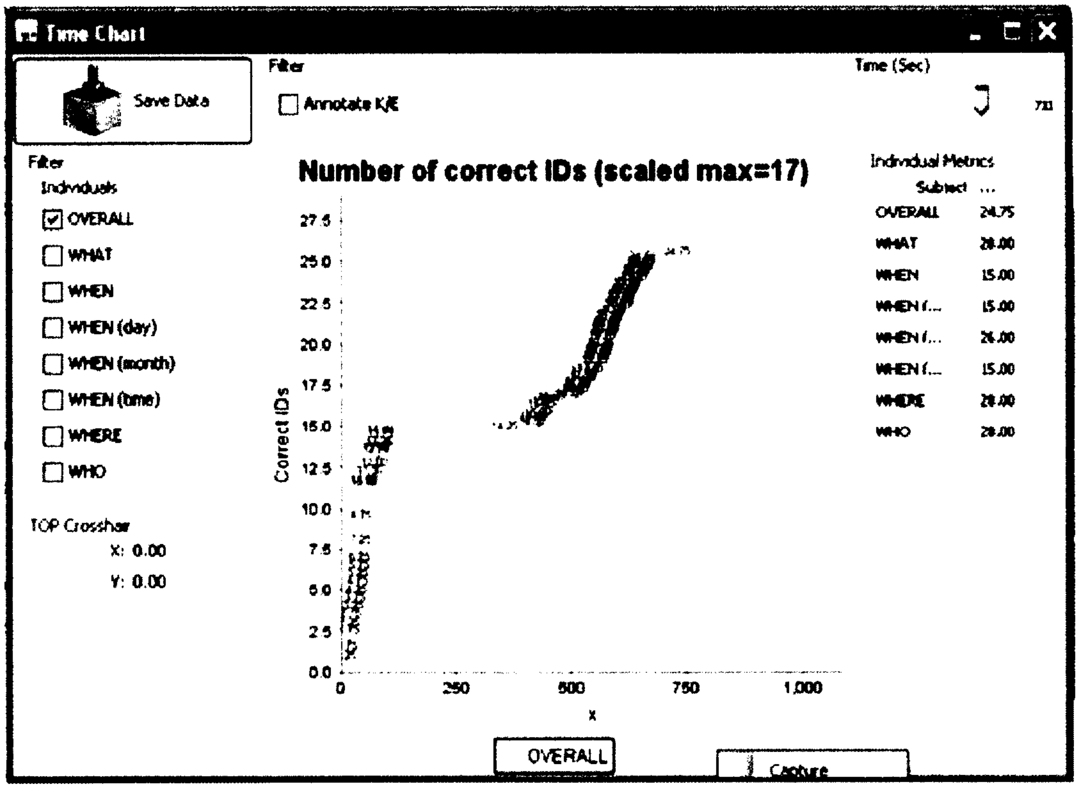



*Figure 44.* 3X System Fragmentation Number of IDs, Nominal

As System Fragmentation becomes obnoxious at three times the initial setting, the nominal organization finds the correct answers at even a faster rate.

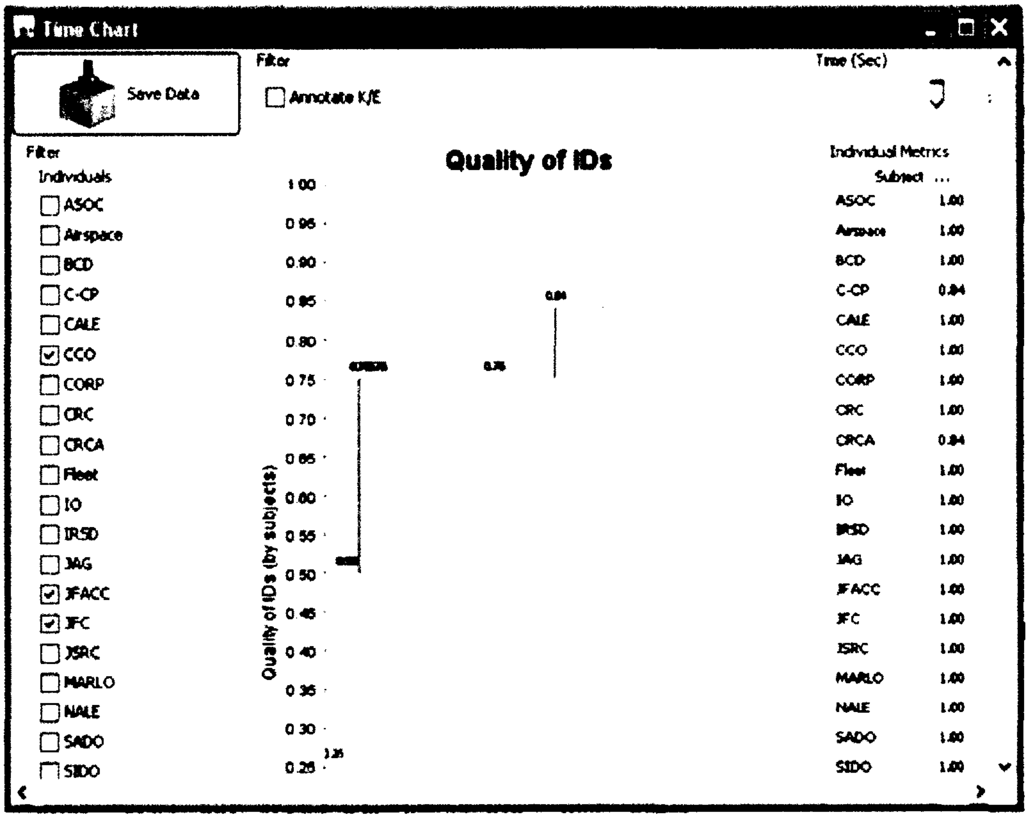



*Figure 45.* 3X System Fragmentation Quality of IDs, Edge

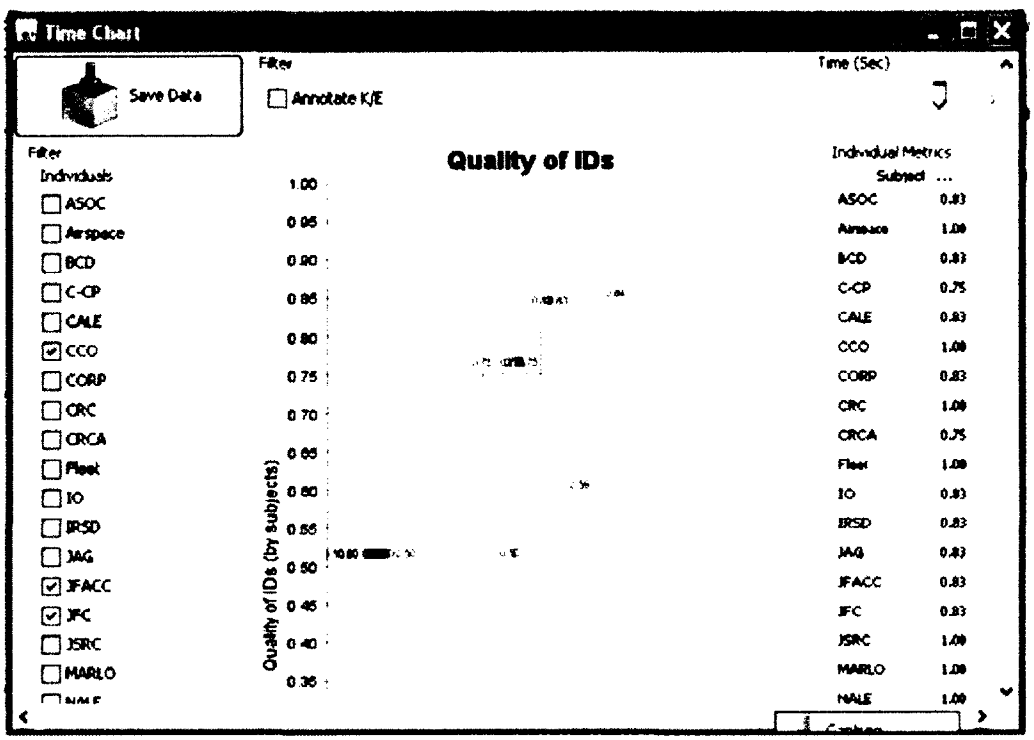



*Figure 46.* 3X System Fragmentation Quality of IDs, Nominal

At triple fragmentation, the Nominal organization still cannot achieve a Quality of ID by all leaders. With triple fragmentation the Quality of ID's have shifted to earlier.

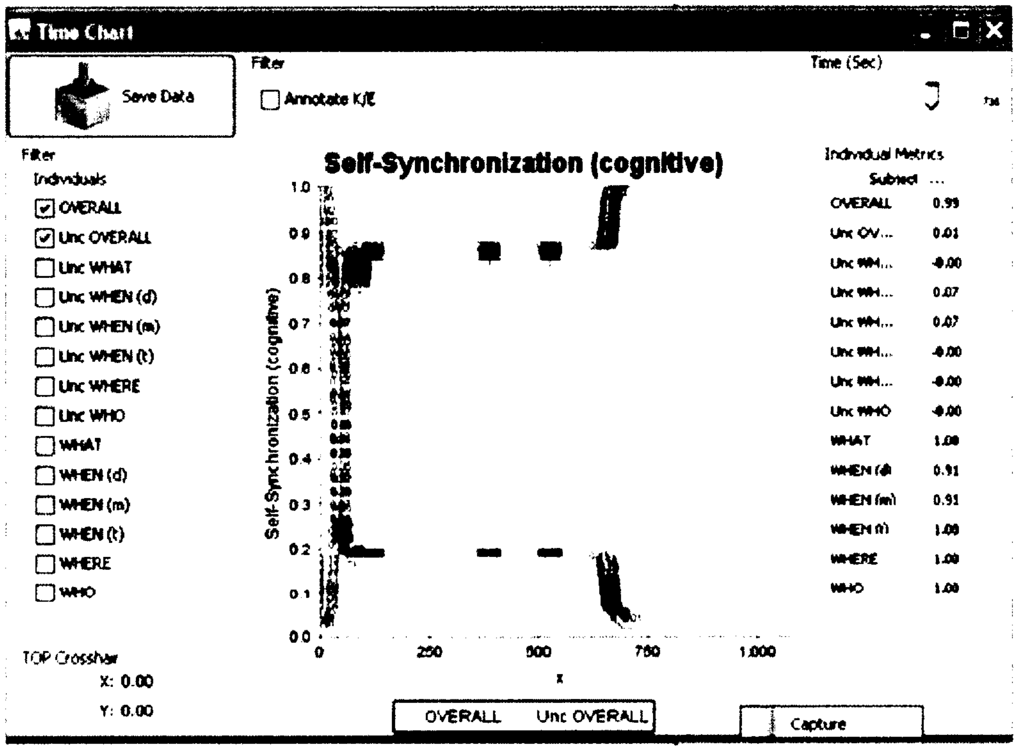



*Figure 47.* 3X Self-Synchronization, Edge

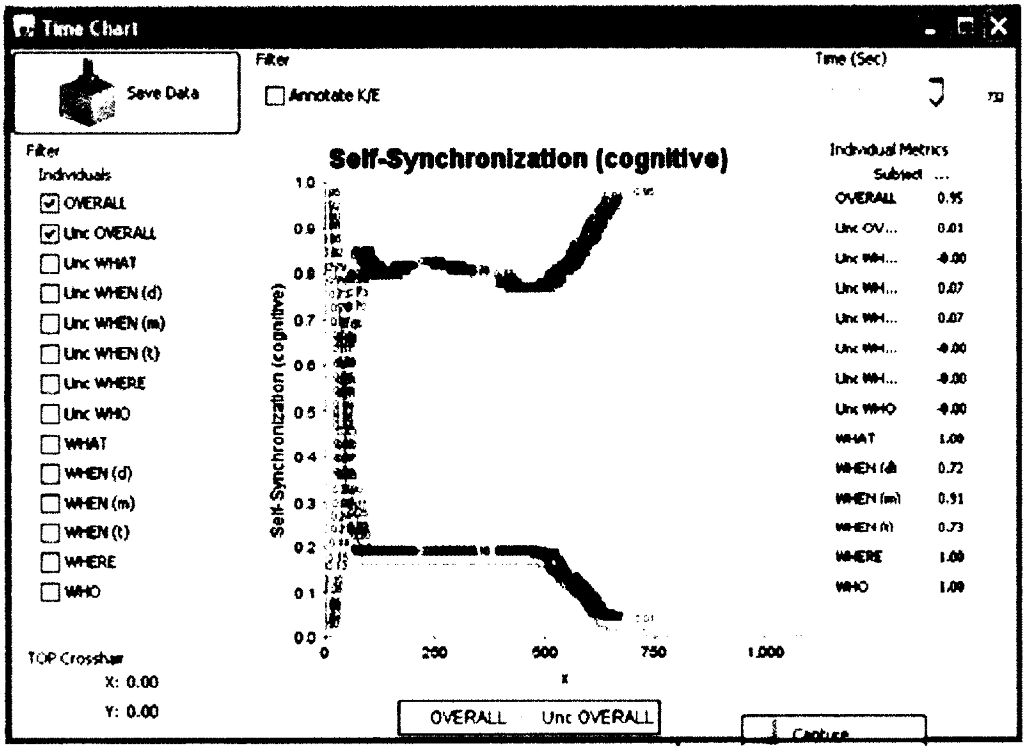



*Figure 48.* 3X Self-Synchronization, Nominal

Continuing to increase system fragmentation has resulted in the Nominal organization experiencing earlier many more individuals synchronizing, but at a certain time in the process the self-synchronization actually decreases. Now I will analyze how increasing noise is reflected in the two different organizational structures.

### 3.5.8 50% Noise, Edge as Compared to Nominal

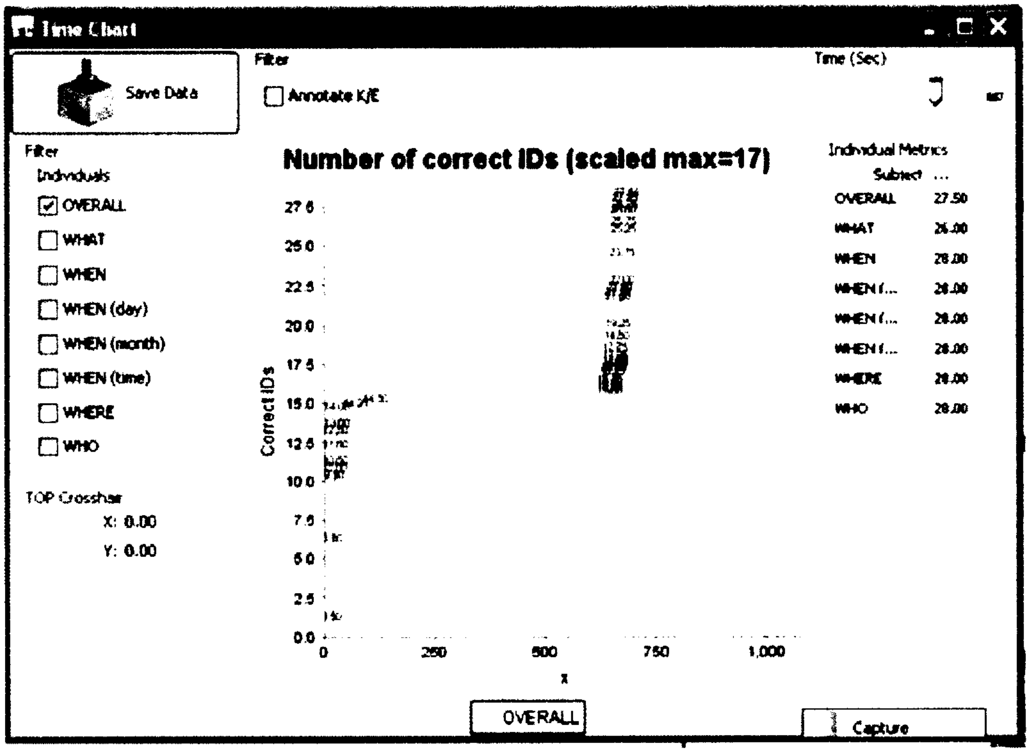



*Figure 49.* 50% Noise Number of IDs, Edge

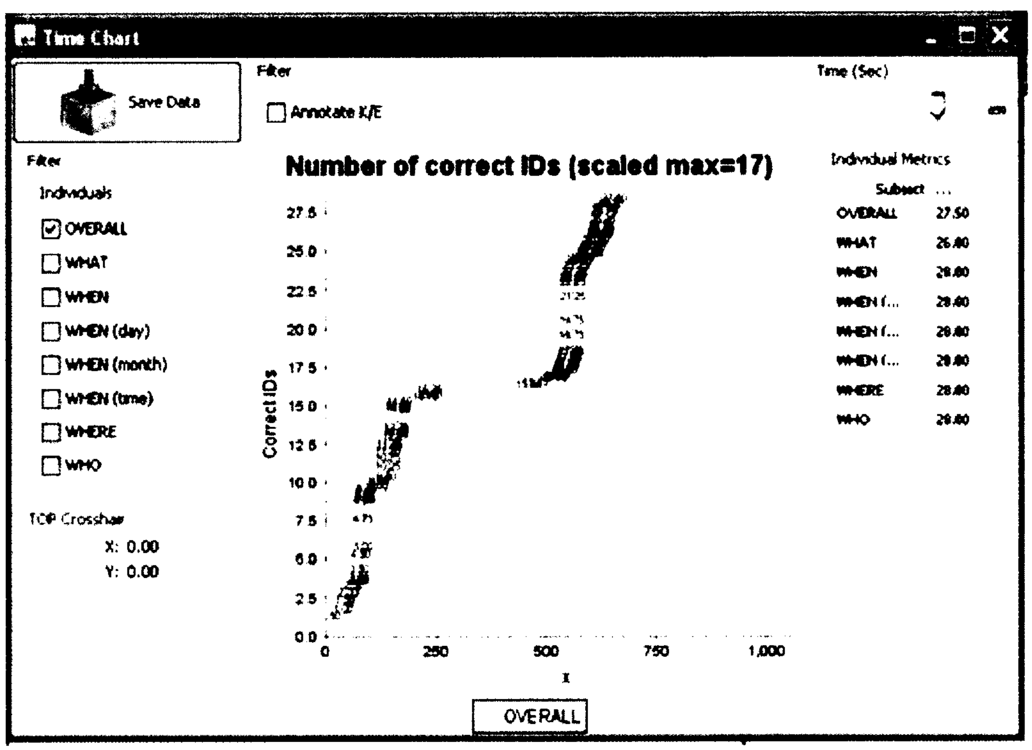



*Figure 50.* 50% Noise Number of IDs, Nominal

In the noise baseline the number of problem solvers are early and late, whereas in the nominal organization all slowly progress toward the answer in a more group centric pattern.

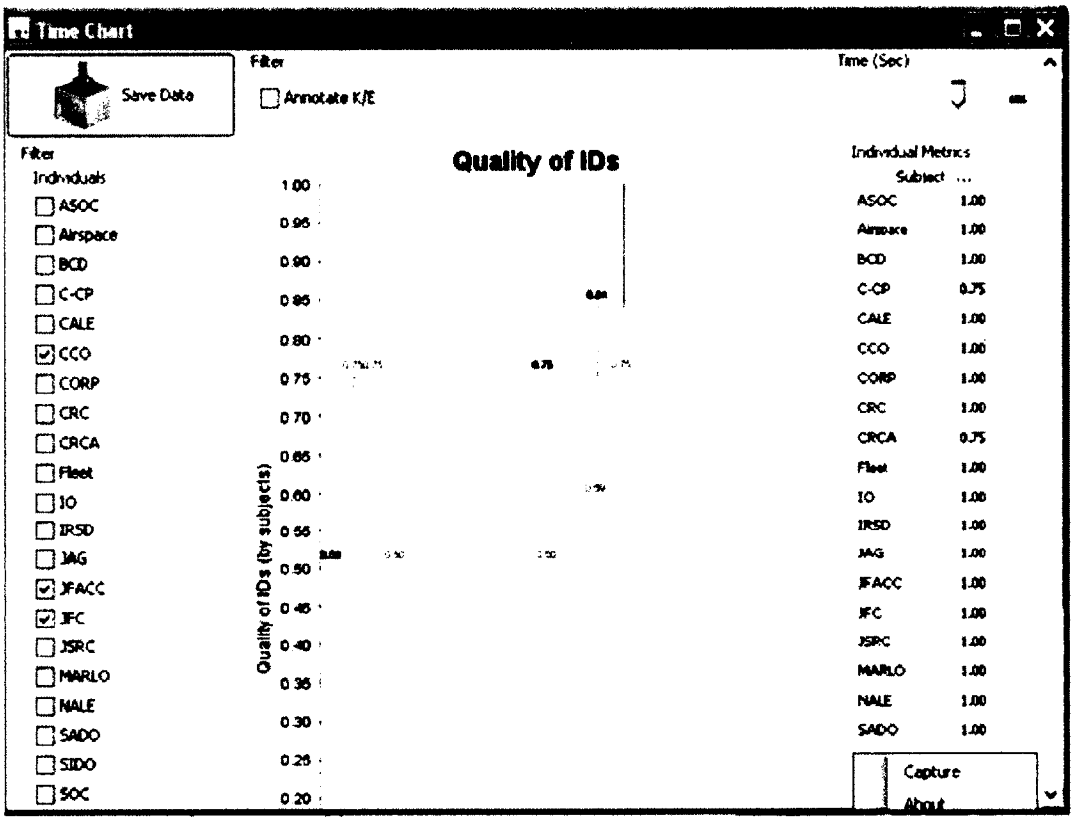



*Figure 51.* 50% Noise Quality of IDs, Edge

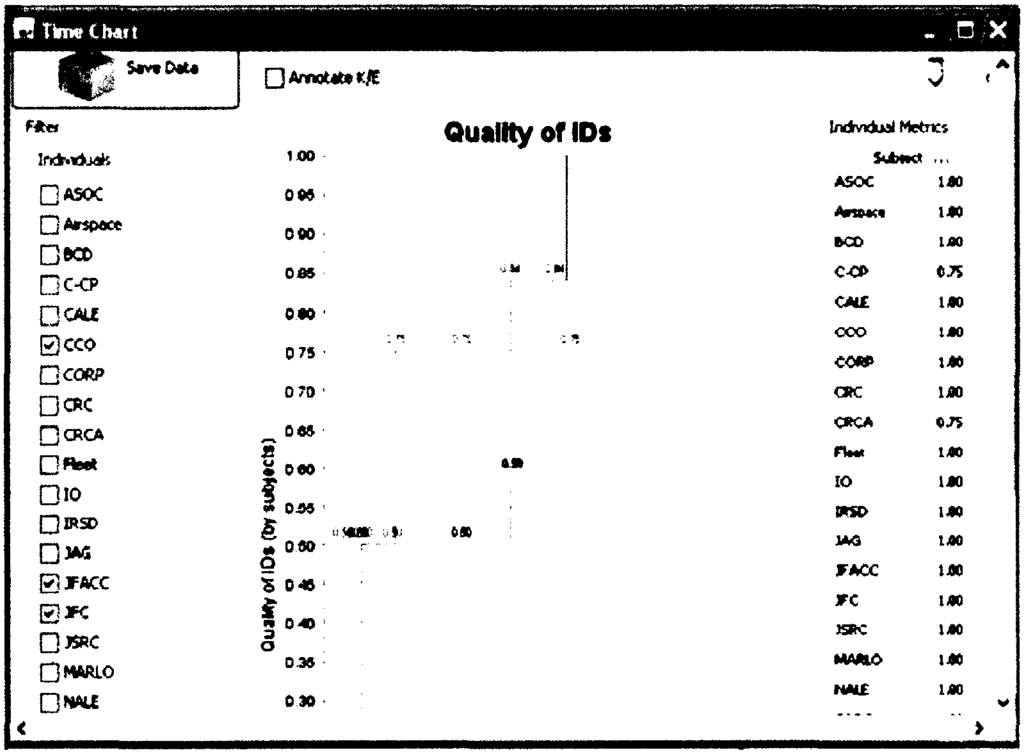



*Figure 52.* 50% Noise Quality of IDs, Nominal

The CCO quality of ID (red line) moves earlier in the baseline noise level event in an Edge organization as compared to the Nominal organization.

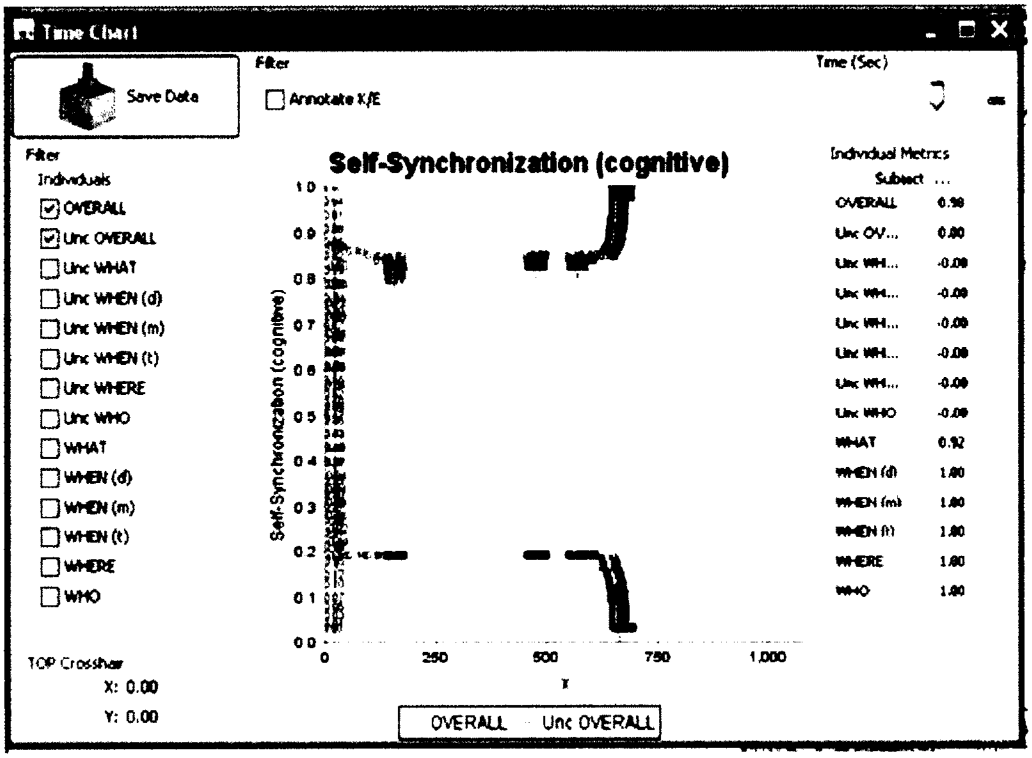



*Figure 53.* 50% Noise Self-Synchronization, Edge

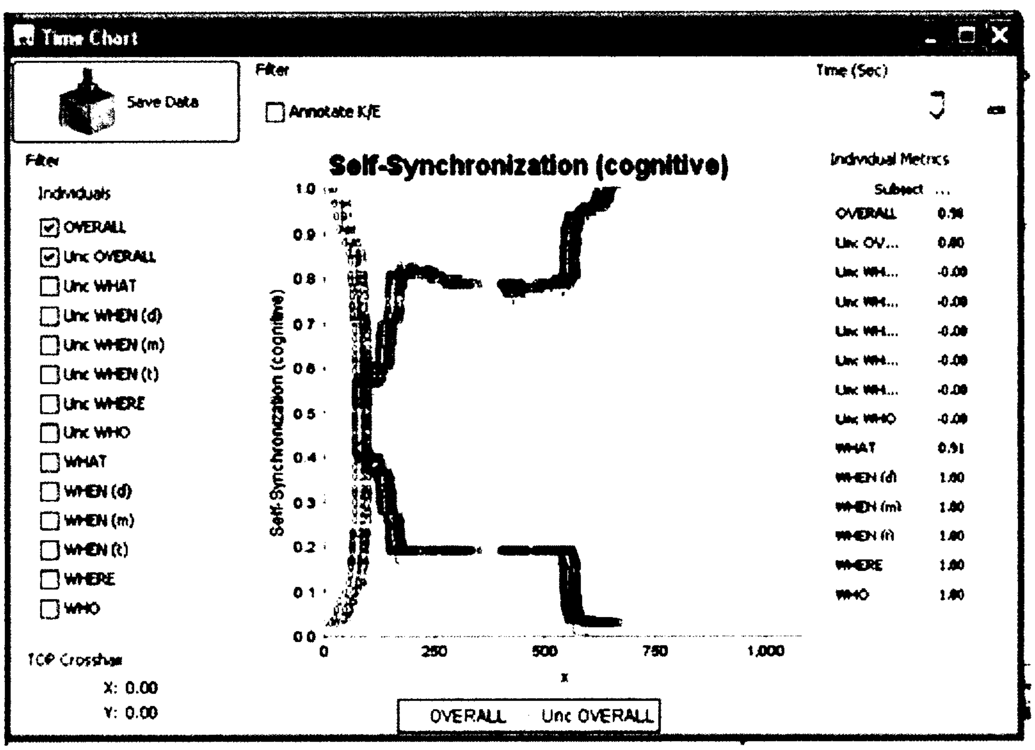



*Figure 54.* 50% Noise Self-Synchronization, Nominal

In both types of organizations (at baseline noise load) self-synchronization happens early and late with self-synchronization happening with an Edge organization earlier in the overall process.

### 3.5.9 66% Noise, Edge as Compared to Nominal

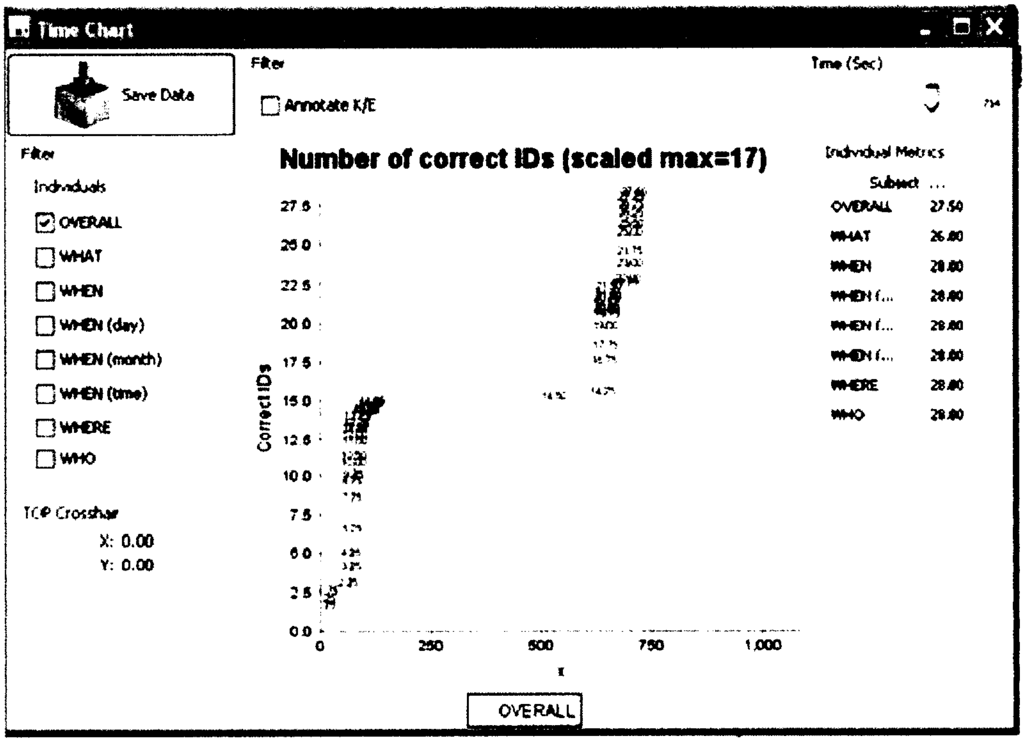



*Figure 55.* 66% Noise Number of IDs, Edge

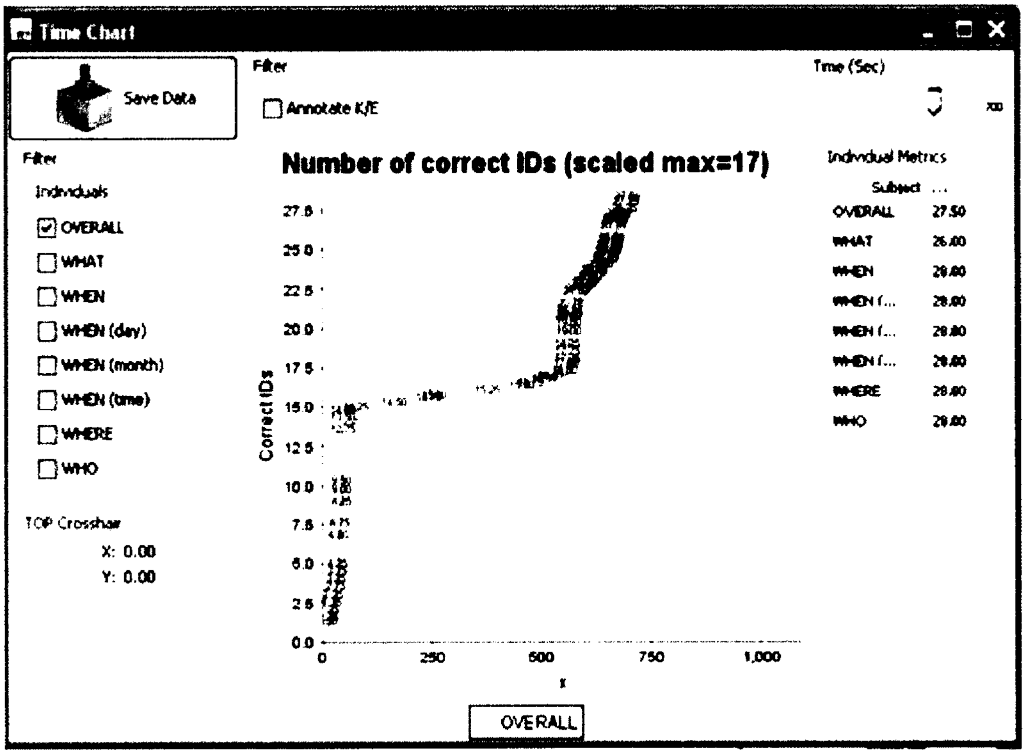



*Figure 56.* 66% Noise Number of IDs, Nominal

As noise increases, the Edge organization tends to plane off in number of correct IDs until the end of the event, whereas the Nominal is always getting better.

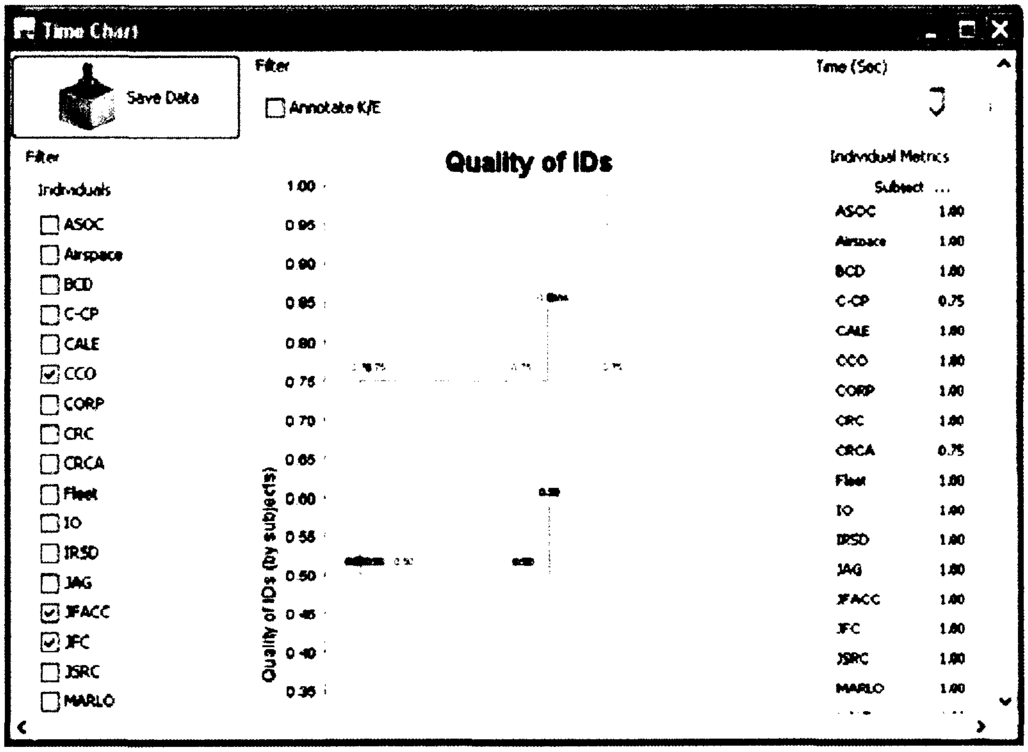



*Figure 57.* 66% Noise Quality of IDs, Edge

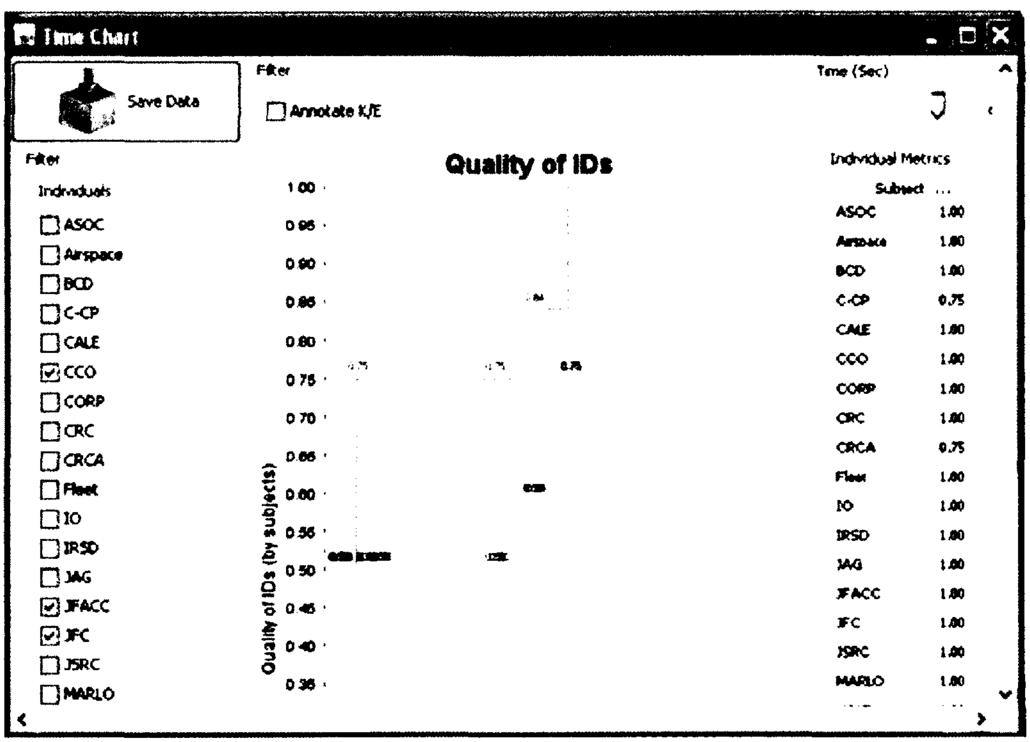



*Figure 58.* 66% Noise Quality of IDs, Nominal

As noise increases, the JFC is late to have quality of ID's in both Edge and Nominal organization.

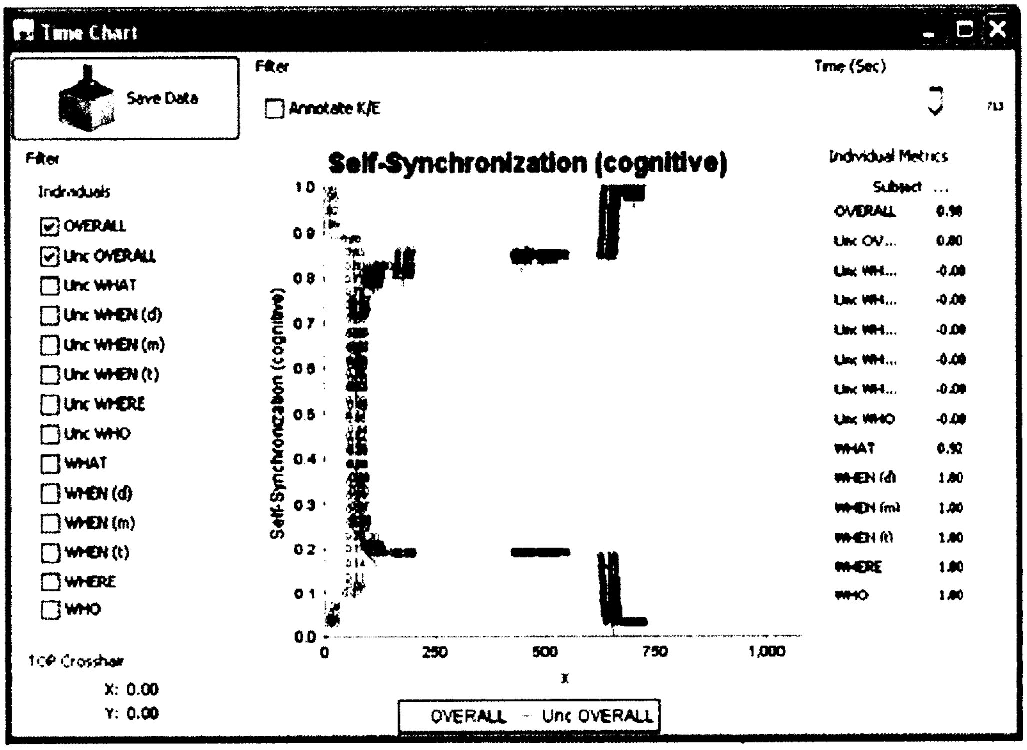



*Figure 59.* 66% Noise Self-Synchronization, Edge

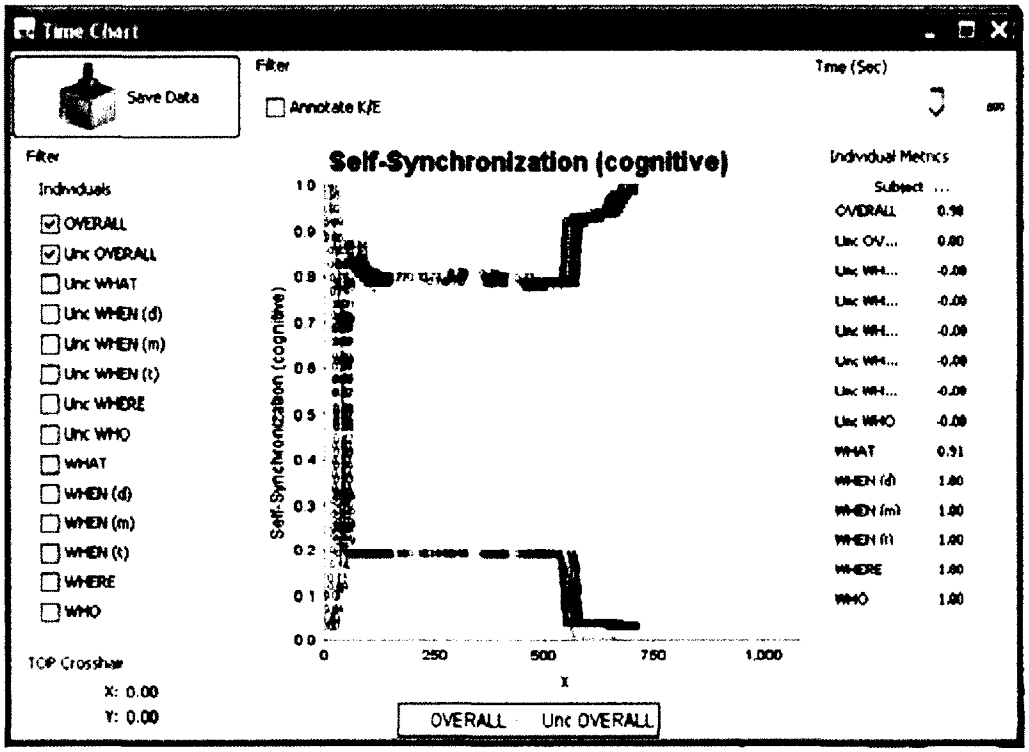



*Figure 60.* 66% Noise Self-Synchronization, Nominal

Increasing noise seems to have no effect on either Edge or Nominal in determining self-synchronization.

### 3.5.10 75% Noise, Edge as Compared to Nominal

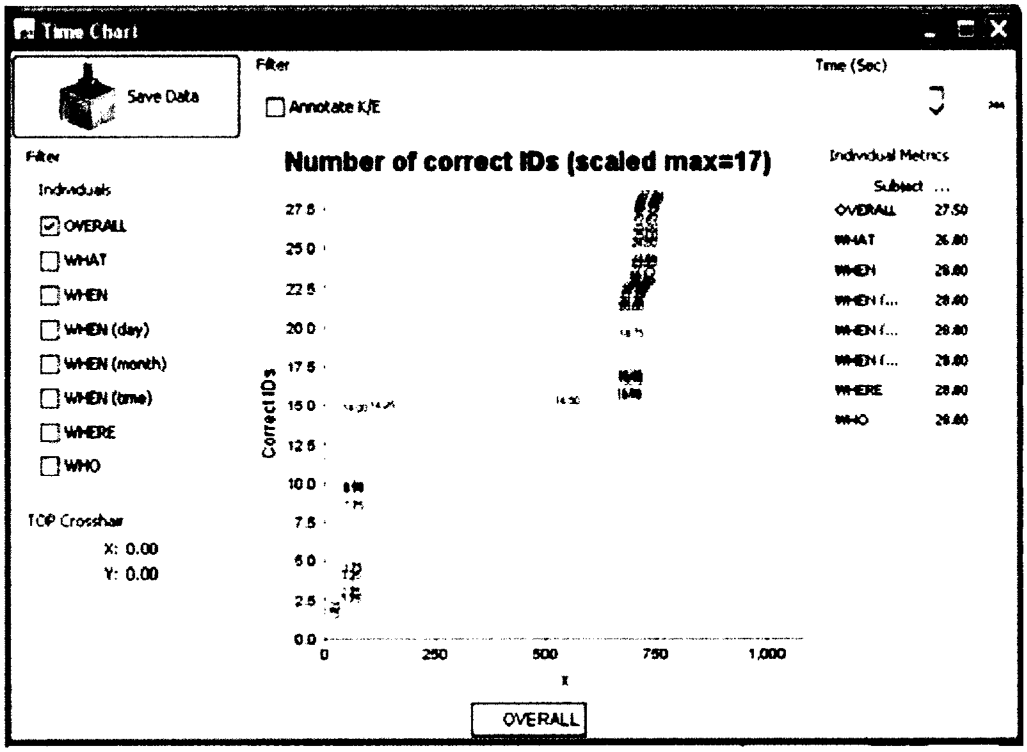



*Figure 61.* 75% Noise Number of IDs, Edge

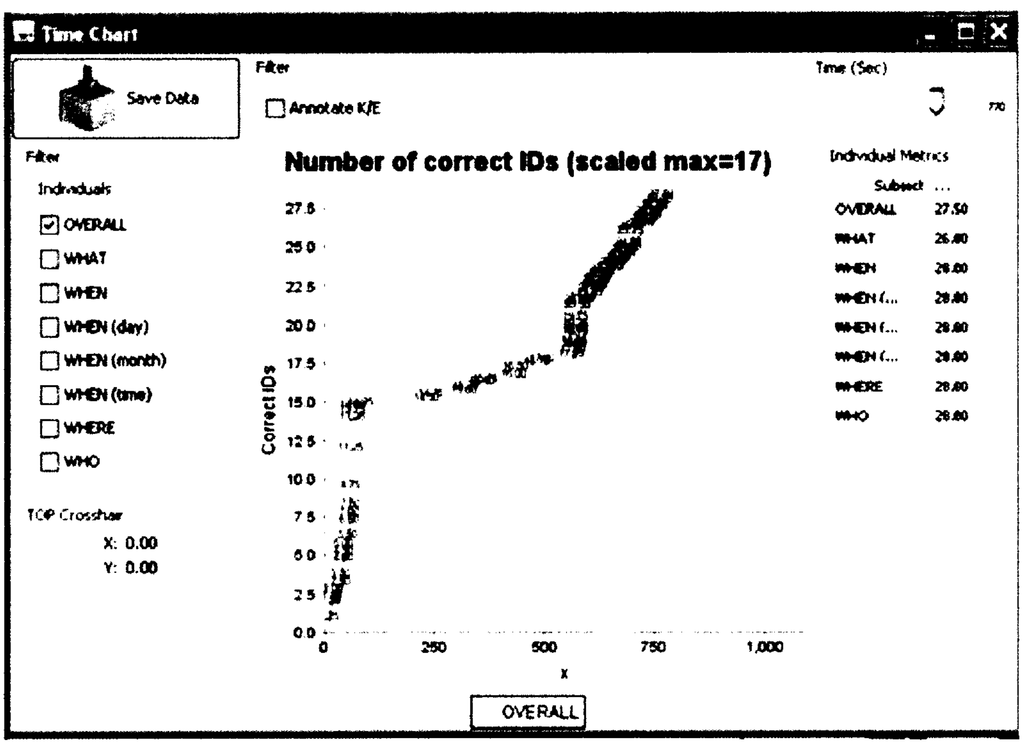



*Figure 62.* 75% Noise Self-Synchronization, Nominal

As noise moves to the extreme, the nominal organization continues to bring all in understanding.

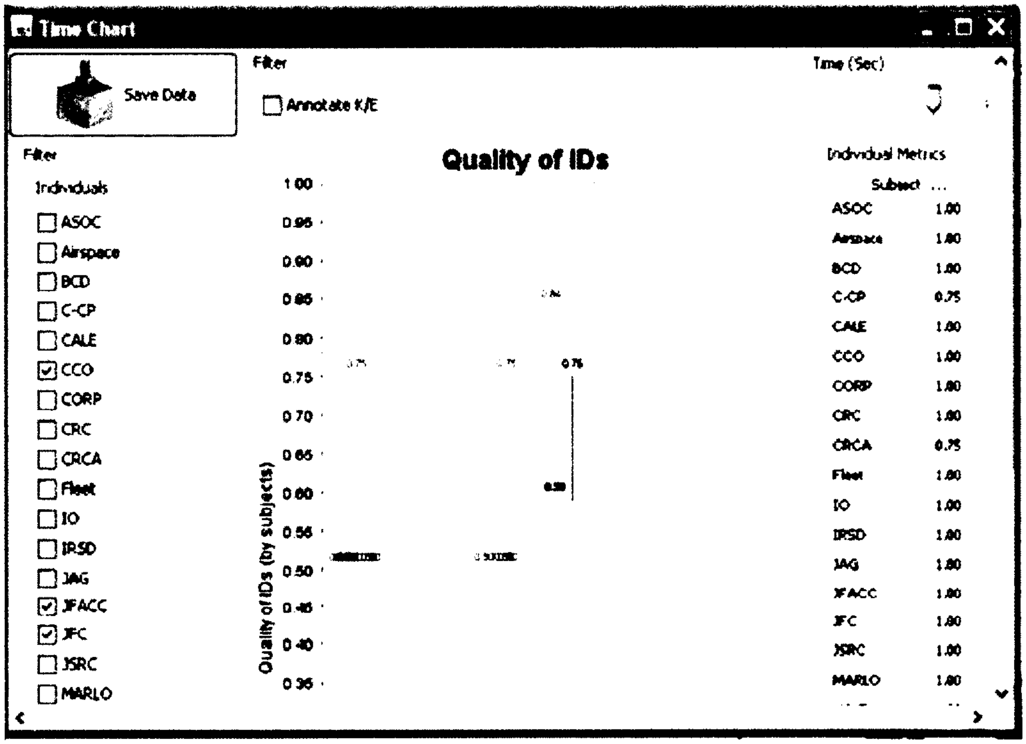



*Figure 63.* 75% Noise Quality of IDs, Nominal

As compared to system fragmentation the CCO, JFACC and JFC all have a high quality of ID. The JFC tends to be later in the Edge organization.

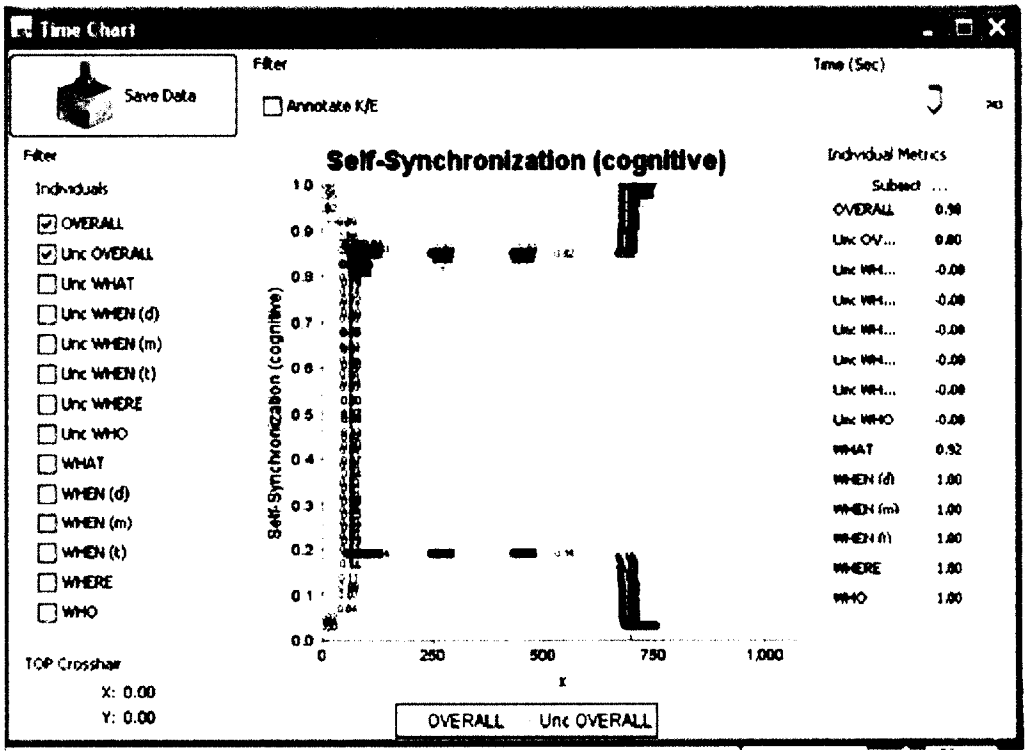



*Figure 64.* 75% Noise Self-Synchronization, Edge

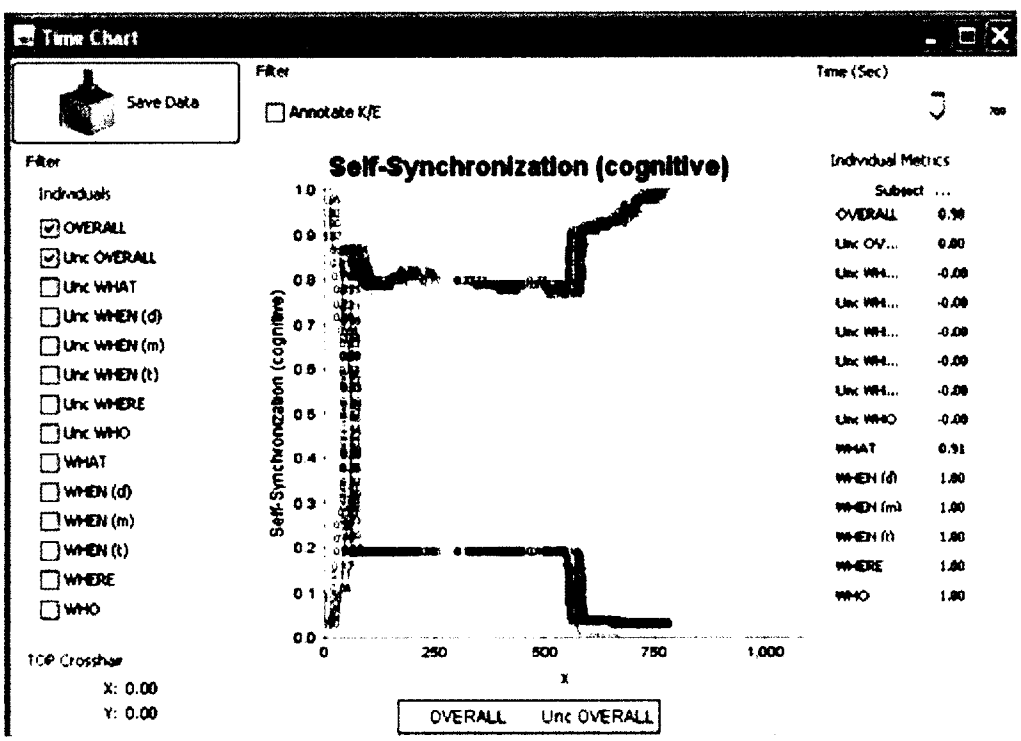



*Figure 65.* 75% Noise Self-Synchronization, Nominal

As noise moves to the extreme, the Nominal organization and Edge organization both tend to level off in the middle of the event with the Nominal picking up sooner in being more self-synchronized.

What this exercise has demonstrated is that there is a relationship between the human decision-making structure and the underlying technical structure. I push the Edge organization to the extreme by having everyone communicate with everyone else, and there are limits to NCW, as not all measures improve moving toward Edge.

### 3.6 TRUSTWORTHINESS AND VALIDITY

This researcher understands the potential exists for criticism concerning validity and trustworthiness of knowledge (research output) elicited through an artificially constructed C2 model study. Accepting and acknowledging that criticisms exist will help to curb known and unknown researcher bias. Only by accounting for potential criticisms is there a chance to mitigate any unattended gaps in research that would result in a dissertation that would have no merit and be a waste of paper, ink, and heartbeats.

ELICIT is the Experimental Laboratory for Investigating Collaboration Information-sharing and Trust. Developed under the Command and Control Research Program (CCRP) within the Office of the DoD CIO, ELICIT uses an online multi-user software platform to conduct experiments and simulations in information-sharing and trust. The configurable ELICIT software platform allows users to precisely model specific Command and Control processes, as well as Edge organization processes and to fully instrument all interactions. The original project objective was to conduct a series of online experiments to compare the relative efficiency and effectiveness of various organizational structures in performing tasks that require decision making and collaboration. The baseline experiment task was to identify the who, what, where and when of an adversary attack based on information factoids that become known to a team.

To date, experiments and have been run with live subjects and software agents at numerous military and civilian locations including Air Force Research Labs, Army Research Labs, Boston University, Harvard, George Mason University, West Point, the Naval Post Graduate School, Naval War College, National Defense University, the Army War College, the Portuguese Military Academy, and in Canada, the UK, Chile, and Singapore. ELICIT exercises are also used as classroom teaching tools.

ELICIT has been developed and refined over a period of eight years. Direct development investment by the CCRP has been approximately two million dollars. Significant additional resources (including human participants) were provided by researchers directly. ELICIT has been vetted and refined by an international group of researchers. The software agents were developed and tuned based on data and experience with live participants. It is rare to have a research platform that supports both human and agent participants. This allows for models to be developed relatively inexpensively with software agents and then validated with humans. Given how difficult it is to arrange for large, suitable, subject pools, even if sufficient funding were available, it would be very difficult to recreate ELICIT.

### 3.7 SIGNIFICANCE OF THE STUDY

The nature of war historically adapts to the technology available. Metaphorically, ancient military operations were more like solid mechanics, and industrial age combat could be well represented by fluid mechanics. The term that best applies to knowledge age combat is 'Cloud' centric, in which a small world of knowledge drives the understanding of battlefield truth. Knowledge age combat will rely on hierarchical silos of systems in which only a few have the full picture of the overall situation because no single individual or organization has yet to prove they can hold and understand the cacophony of available data. I designed this research to understand some of the core issues associated with operational Air Power C2 in the information age and to develop a conceptual framework to analyze improving operational capability. The assumption is the AOC is comprised of two networks, the technical (data/information flow) and human (defined by social networking where decisions are made), with limited touch points. One of the goals of this effort was to use ELICIT and artificial software agents to vary AOC data flow (increasing noise and system fragmentation/network fragmentation) and measure the change with social networking metrics. Another was to vary organizational structure (Nominal and Edge) to determine the correlation to overall data/information flow through the system. Using ELICIT is an attempt to move C2 research from a qualitative model towards a quantitative model with some repeatability as a validation metric.

In the battle for Crete in World War II, the British broke the German crypto code and knew who was coming, when they were coming, and how strong they would be – and they still lost the battle. Having better C2 may not win battles or wars. Therefore, the study of C2 is a relevant subject for a PhD dissertation and is a subject that is worthy of a lifetime of inquiry. We are on the cusp of the knowledge age. What that means for the face of conflict is yet to be determined.

What can be determined is the significance of this work as part of the C2 knowledge base. This paper provides three distinct practical vectors:

1) Theoretical - Binding theory by joining Social Networking Theory and Information Theory into a single framework for evaluation. I used the resulting conceptual framework to accomplish foundational research on a representative Air Power C2 node. By using this new conceptual framework, I have accomplished a quantitative evaluation by something other than mission treads, field exercise, or actual combat. This foundational work has the potential to lead to understanding the value or lack of value of a C2 approach.
2) Methodological – I used a case study research technique in a System of Systems venue designed to advance the Engineering Management discipline. My method is to use information theory supporting nuclear power plants as a conceptual framework for a case study researching an operational level military node. I used social networking measures as a framework to determine organizational improvement in an operational level military node. The outcome is to use both information theory and social networking concepts in a non-traditional setting.
3) Practical – There is hope that this research could start the process required to achieve some sort of federated C2 structure, in particular, how to explore the JFACC- Forward concept operationally. A concrete outcome would be to create a measure that can be used on any distributed C2 environment that could be incorporated into Operational Testing (OT), design, and experimentation of new C2 systems.

### 3.8 SUMMARY

The fallacy of creating a flat earth of information where the operator has access to a 1-to-1 representation of reality may result only in the human operator quickly becoming the organizational single point of failure. In an open bandwidth milieu, an ever-increasing number of levels of networks based on security and system/sub-system segmentation is a vital venue for research. The power and advantage of the knowledge age is best represented by the time it took to change the standard operating principle of 'give the hijacked plane to the hijackers' to 'fight the hijackers to the best of your ability.'

Therefore, the purpose of this study is to conduct an analysis of a representative Air Power Operational C2 node using a case study designed to elicit fundamental understanding. The goal is to determine how a representative AOC C2 system changes varying noise and system fragmentation when operating in either a Nominal or Edge organizational construct. To do this, I answered two questions: 1) what conceptual framework can be constructed using social networking theory and information theory to evaluate a representative Air Power C2 node, and 2) what elucidation results from the application of the framework on a representative C2 node?

Contingency theory states that there is no best way to organize; not all ways to organize are equally effective. The theory states qualitative rules observed through research on how companies organized in specific contexts and how organizations with different structures perform in those contexts.

My research gnaws at the core tenets of C2 in the information age and accomplishes the fundamental research and validation that needs to take place. The critical question I search for is to determine if the tenets of Network Center Warfare are unbounded. Initial research of command and control decision-making have tended to indicate either that information had little effect on decision-making, or that any effects from information were dominated by variability between decision makers (Daniel, Holt, & Mathieson, 2002; Mathieson, 2001).

Others researchers call out in loud voices for this type of research. For instance, Tolk, Bair, and Diallo (2013) state:

> Interoperability of two systems implies mathematical equivalency of their conceptualization. In other words, interoperability is only given in the intersection of two systems. This is counterintuitive to many current views that assume that by interoperability the union of the provided capabilities becomes available. We therefore need an operational frame that helps to orchestrate individual and independent technical solutions. (p. 5)

This research does not just deal with a US model; it brings in joint and coalition members and looks at the interaction. The research tries to determine if too much or too little of a good thing (data/information) impacts organizational performance.

# CHAPTER FOUR - RESULTS

The importance of the results is not the values resulting from a detailed analysis of the data provided. This case study was exploratory in nature to gain basic elicitation. I was able to create a conceptual model, and from that I was able to derive how to organize a physical model that represents air power at the operational level of war. A CST bound literature review developed Network Centric Warfare as the key C2 tenant moving toward the future. By using a pluralist approach, I have epistemologically defined an unexplored relationship between the C2 system and the people that use them. By increasing noise and system fragmentation in a valid C2 operational model and getting results, I have proved there is a measurable relationship between C2 systems and the human decision organization, which may be greater than mere correlation. I pushed the model organization from a Nominal structure to an extreme "Edge" organization. According to John Scott (1991), one should expect that many weak ties are more likely to introduce new information and differing perspectives than tightly closed networks with many redundant ties. It other words it is better to have connections to a variety of networks than many connections in a single network. Robin Dunbar suggested that a human network is perhaps limited to about 150 members due to the physical capacity of humans. Mark Granovetter (2007) found there are homophilic tendencies in any clique where each member of the clique knows more or less what the other members know. Was one of these factors or were hundreds of other factors responsible for the change in my C2 measurements? Future research can quantitatively decide those relationships. What I have proven is there is a need to seek to understand the fundamentals and expected key C2 results as we move deeper into the Information Age. The following network results legitimize organizational structure changes the measurable C2 factors in an AOC.

## 4.1 ORGANIZATIONS

Edge organization structure results are as depicted below (each 1 represents possible communication path). It is easy to see how far I have pushed this organization:

| Agent | ASOC | Airspace | BCD | C-CP | CALE | CCO | CORP | CRC | CRCA | Fleet | IO | IRSD | JAG | JFACC | JFC | JSRC | MARLO | NALE | SADO | SIDO | SOC | SODO | SOLE | Space | TACC | Tanker | WOC | WX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ASOC | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Airspace | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| BCD | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| C-CP | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| CALE | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| CCO | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| CORP | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| CRC | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| CRCA | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Fleet | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| IO | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| IRSD | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| JAG | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| JFACC | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| JFC | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| JSRC | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| MARLO | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| NALE | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| SADO | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| SIDO | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| SOC | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| SODO | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 |
| SOLE | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 |
| Space | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 |
| TACC | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 |
| Tanker | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 |
| WOC | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 |
| WX | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | |

*Figure 66.* Edge organization structure results

The following visual depiction of the same Edge organization:

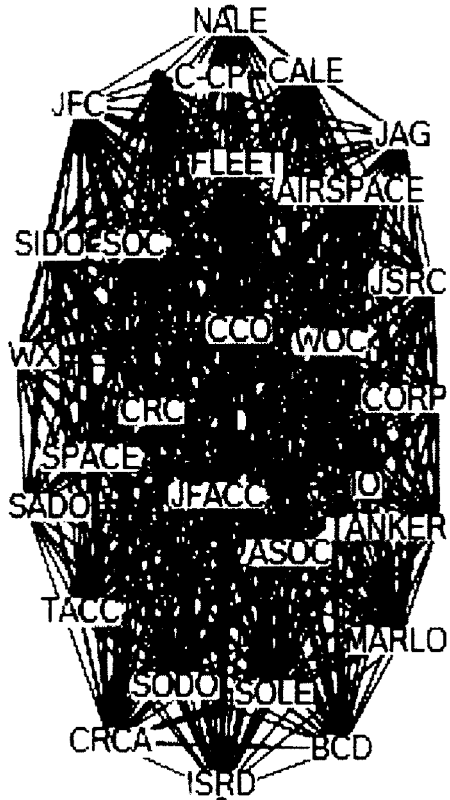
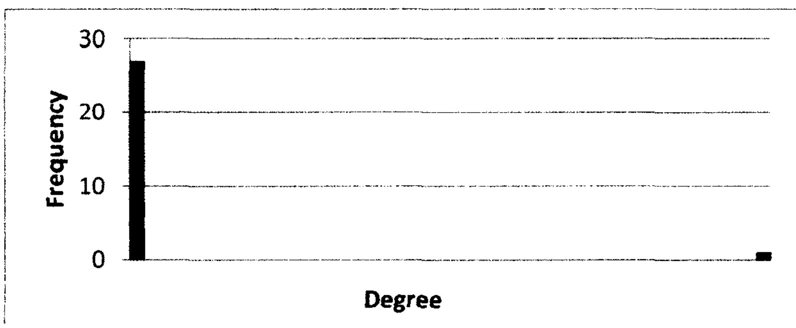



*Figure 67.* Visual depiction of Edge organization structure results

In my Edge construct, each organization/individual has symmetric communications with all. This would imply total data sharing. It is the Sirens call toward the rocks that total Edge offers.

*Table 17.* Edge Organization Results

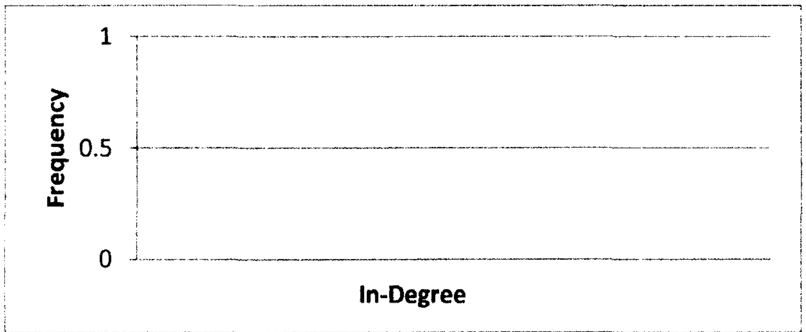
| Graph Type | Undirected |
|---|---|
| Vertices | 28 |
| Unique Edges | 1 |
| Edges With Duplicates | 783 |
| Total Edges | 784 |
| Self-Loops | 1 |
| Reciprocated Vertex Pair Ratio | Not Applicable |
| Reciprocated Edge Ratio | Not Applicable |
| Connected Components | 1 |
| Single-Vertex Connected Components | 0 |
| Maximum Vertices in a Connected Component | 28 |
| Maximum Edges in a Connected Component | 784 |
| Maximum Geodesic Distance (Diameter) | 1 |
| Average Geodesic Distance | 0.964286 |
| Graph Density | 1 |
| Modularity | Not Applicable |
| NodeXL Version | 1.0.1.245 |



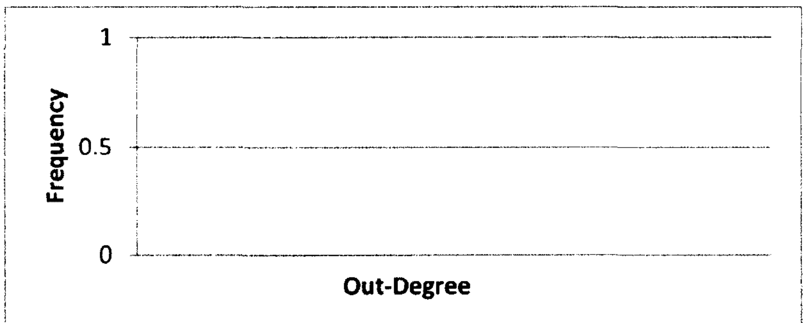

| | |
|---|---|
| Minimum Degree | 27 |
| Maximum Degree | 29 |
| Average Degree | 27.071 |

Table 11 (continued)

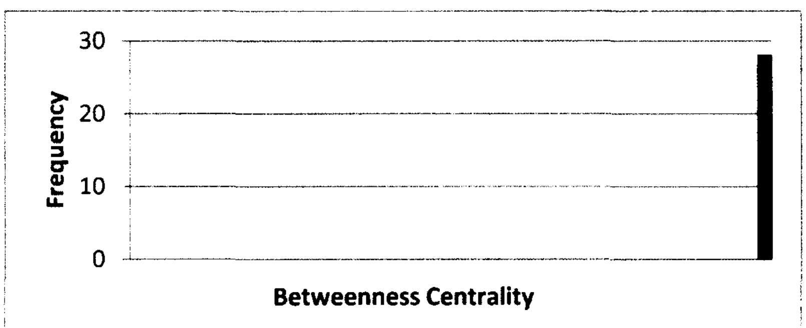
| | |
|---|---|
| Median Degree | 27.000 |




| | |
|---|---|
| Minimum In-Degree | Not Available |
| Maximum In-Degree | Not Available |
| Average In-Degree | Not Available |
| Median In-Degree | Not Available |

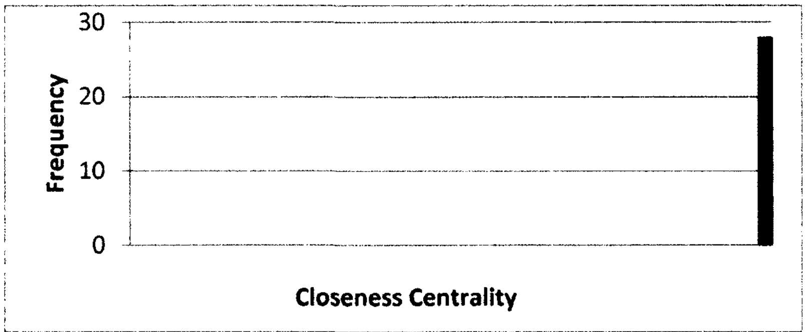



| | |
|---|---|
| Minimum Out-Degree | Not Available |
| Maximum Out-Degree | Not Available |
| Average Out-Degree | Not Available |
| Median Out-Degree | Not Available |

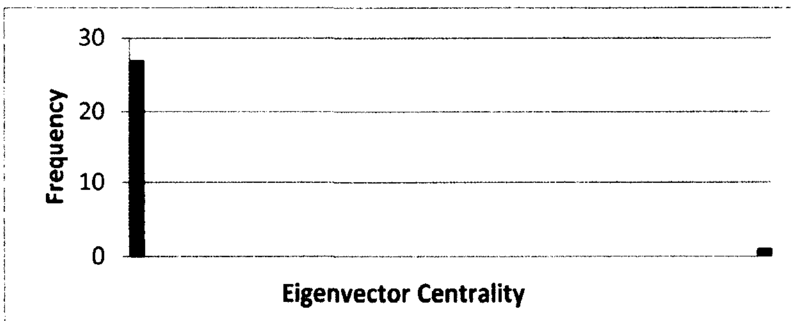



| | |
|---|---|
| Minimum Betweenness Centrality | 0.000 |
| Maximum Betweenness Centrality | 0.000 |
| Average Betweenness Centrality | 0.000 |
| Median Betweenness Centrality | 0.000 |

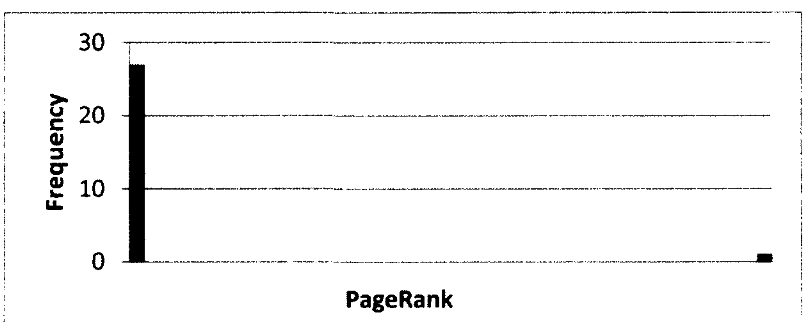
Table 11 (continued)




| | |
|---|---|
| Minimum Closeness Centrality | 0.037 |
| Maximum Closeness Centrality | 0.037 |
| Average Closeness Centrality | 0.037 |
| Median Closeness Centrality | 0.037 |

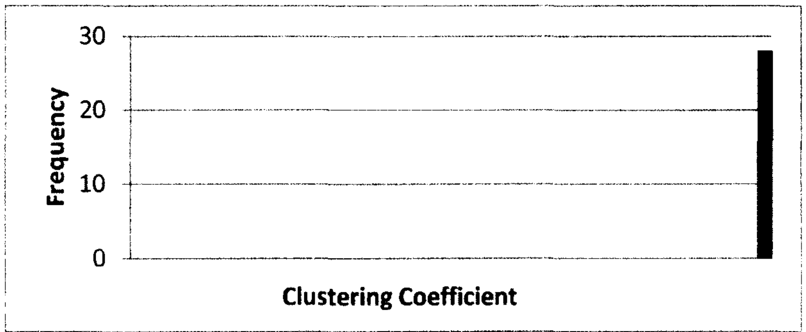



| | |
|---|---|
| Minimum Eigenvector Centrality | 0.036 |
| Maximum Eigenvector Centrality | 0.037 |
| Average Eigenvector Centrality | 0.036 |
| Median Eigenvector Centrality | 0.036 |




| | |
|---|---|
| Minimum PageRank | 0.999 |
| Maximum PageRank | 1.030 |
| Average PageRank | 1.000 |
| Median PageRank | 0.999 |

Table 11 (continued)




| | |
|---|---|
| Minimum Clustering Coefficient | 1.000 |
| Maximum Clustering Coefficient | 1.000 |
| Average Clustering Coefficient | 1.000 |
| Median Clustering Coefficient | 1.000 |

Nominal organization structure results are (each 1 represents a possible communication path):

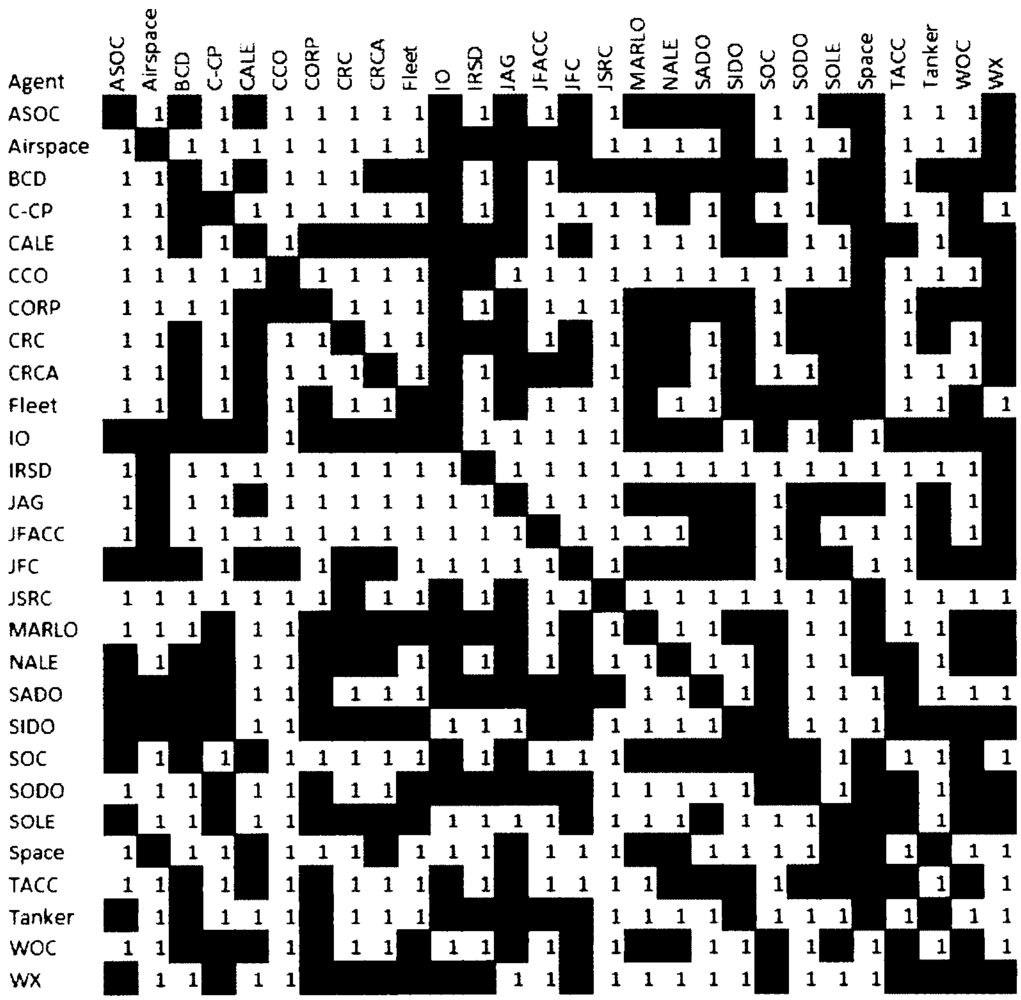



*Figure 68.* Nominal organization structure results

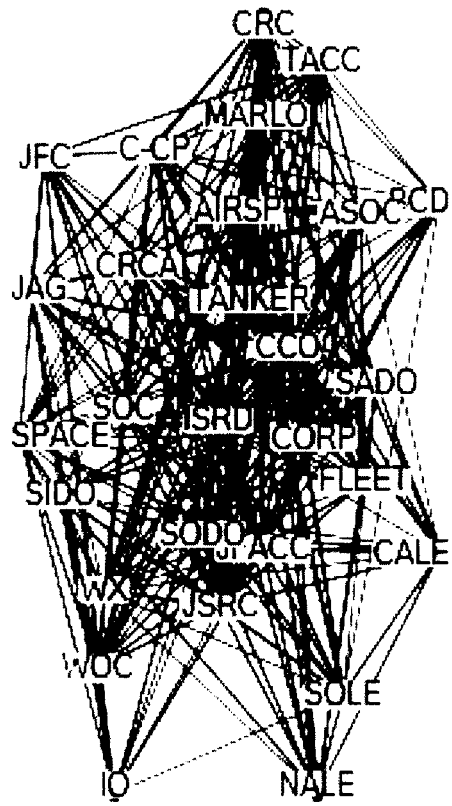
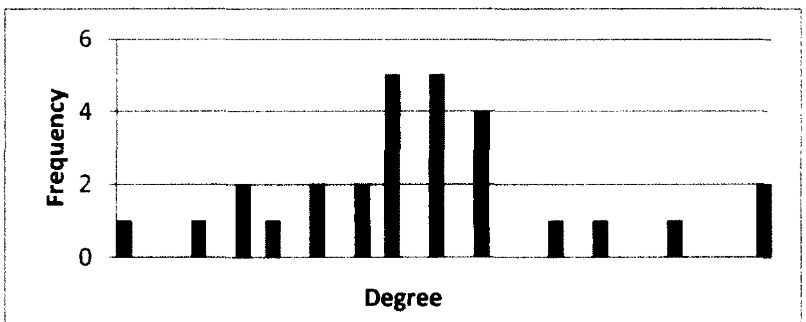



*Figure 69.* Visual depiction of Nominal organization structure results

*Table 18.* Nominal organization results

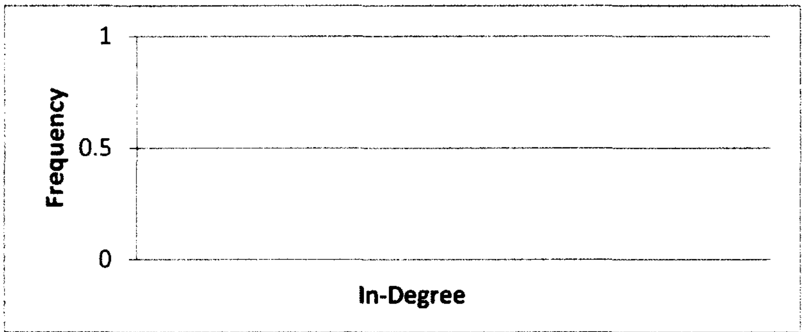
| Graph Type | Undirected |
|---|---|
| Vertices | 28 |
| Unique Edges | 85 |
| Edges With Duplicates | 352 |
| Total Edges | 437 |
| Self-Loops | 0 |
| Reciprocated Vertex Pair Ratio | Not Applicable |
| Reciprocated Edge Ratio | Not Applicable |
| Connected Components | 1 |
| Single-Vertex Connected Components | 0 |
| Maximum Vertices in a Connected Component | 28 |
| Maximum Edges in a Connected Component | 437 |
| Maximum Geodesic Distance (Diameter) | 2 |
| Average Geodesic Distance | 1.262755 |
| Graph Density | 0.69047619 |
| Modularity | Not Applicable |
| NodeXL Version | 1.0.1.245 |



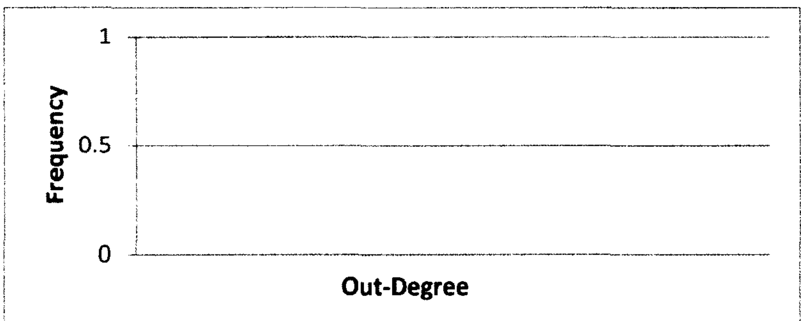

| | |
|---|---|
| Minimum Degree | 11 |
| Maximum Degree | 27 |
| Average Degree | 18.643 |

Table 12 (continued)

| | |
|---|---|
| Median Degree | 18.500 |



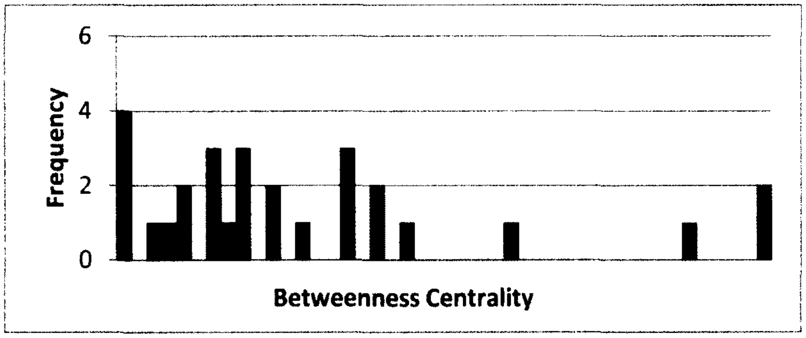

| | |
|---|---|
| Minimum In-Degree | Not Available |
| Maximum In-Degree | Not Available |
| Average In-Degree | Not Available |
| Median In-Degree | Not Available |



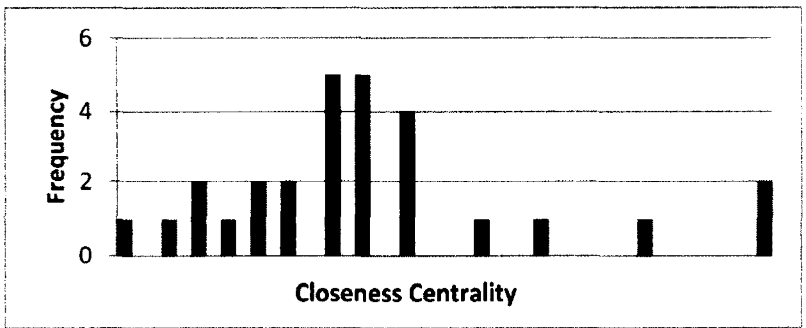

| | |
|---|---|
| | Available |
| Maximum Out-Degree | Not Available |
| Average Out-Degree | Not Available |

Table 12 (continued)

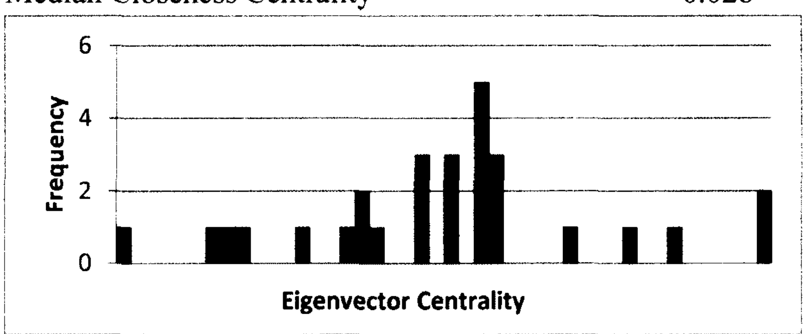
| | |
|---|---|
| Median Out-Degree | Not Available |




| | |
|---|---|
| Minimum Betweenness Centrality | 0.881 |
| Maximum Betweenness Centrality | 12.145 |
| Average Betweenness Centrality | 4.179 |
| Median Betweenness Centrality | 3.125 |

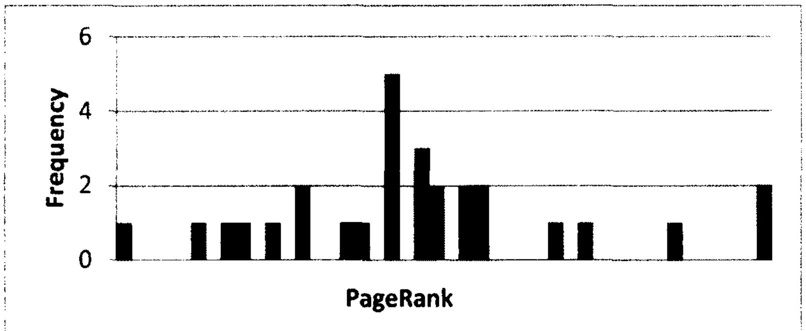



| | |
|---|---|
| Minimum Closeness Centrality | 0.023 |
| Maximum Closeness Centrality | 0.037 |
| Average Closeness Centrality | 0.029 |
| Median Closeness Centrality | 0.028 |

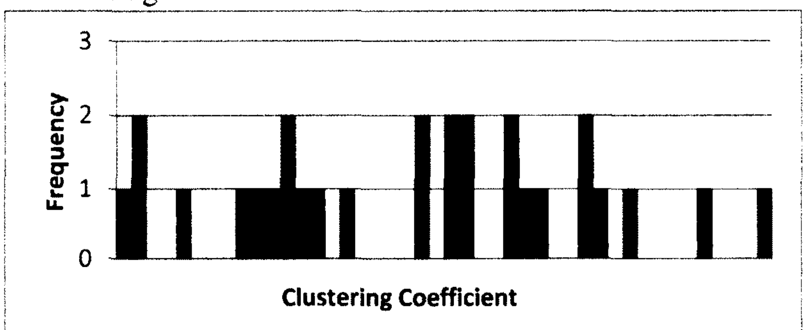



| | |
|---|---|
| Minimum Eigenvector Centrality | 0.021 |
| Maximum Eigenvector Centrality | 0.049 |
| Average Eigenvector Centrality | 0.036 |
| Median Eigenvector Centrality | 0.036 |

Table 12 (continued)




| | |
|---|---|
| Minimum PageRank | 0.652 |
| Maximum PageRank | 1.390 |
| Average PageRank | 1.000 |
| Median PageRank | 0.990 |




| | |
|---|---|
| Minimum Clustering Coefficient | 0.657 |
| Maximum Clustering Coefficient | 0.892 |
| Average Clustering Coefficient | 0.766 |
| Median Clustering Coefficient | 0.775 |

### 4.1.2 Master Data Chart

When I first started working with ELICIT there was only one analysis tool. The tool provided quantitative results and in some cases, I had to manually manipulate the results to display them in a graphic form. The goal all along was to use C2 measurements that had validity in the community. At the end of the project a new ELICIT graphic analysis tool became available and output of the new tool was already in accepted measurements of C2. The following Master Data chart was the data captured before the new ELICIT analysis tool (see images starting on Page140) was available. Whether evaluating the data in the Master Data Chart or evaluating the graphic output provided by the newest ELICIT analysis tool both results point to the same conclusion: When there is a change in either organizations or C2 systems that support them, there is a measurable C2 effect. We may never have a common definition of C2, but that should not be a barrier to measuring and making better the overall socio-technical macro system used to execute combat air power.

*Table 19.* Master Data Chart (Edge) – General Measures

| General Measurements | | | EDGE | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Name** | **Description** | **Value Type** | **1X System Fragmentation (75% Noise)** | **2X System Fragmentation (75% Noise)** | **3X System Fragmentation (75% Noise)** | **0% Noise** | **50% Noise** | **66% Noise** | **75% Noise** | **1X System Fragmentation + 50% Noise Best Cast** | **3X System Fragmentation + 75% Noise Worst Case** |
| Duration | Duration of a run (in agent's time, measured in Minutes) | Number (Run-Info) | 18m 6.852s | 18m 0.937s | 18m 9.734s | 18m 0.38s | 18m 0.536s | 18m 1.067s | 18m 1.872s | 18m 0.536s | 18m 9.734s |
| Compression factor | Compression of time used to accelerate agent runs (e.g. 0.1 means 1 minute in agents time is 10 minutes in human's time) | Number (Run-Config) | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| Total Shares | Number of shares performed by all members | Number (Event-Summary) | 6456 | 4583 | 4556 | 2281 | 8384 | 7708 | 6456 | 8384 | 4556 |
| Total Posts | Number of posts performed by all members | Number (Event-Summary) | 267 | 178 | 258 | 63 | 256 | 267 | 267 | 256 | 258 |
| Total Pulls | Number of pulls performed by all members | Number (Event-Summary) | 2503 | 4838 | 7662 | 6318 | 2996 | 2784 | 2524 | 2996 | 7662 |
| Total IDs | Number of IDs performed by all members | Number (Event-Summary) | 193 | 185 | 178 | 193 | 164 | 195 | 195 | 164 | 178 |
| List of Sense Making agent files | Filename of agents file configuration | Text (Run-Config) | see Sheet 2 | see Sheet 2 | see Sheet 2 | see Sheet 2 | | | | | |
| Workload | Measured as the number of actions requiring information processing work, that is, number of share received actions, pull actions and direct distributions | Number (Event-Summary-Total) (all columns except First Post) | 21945 | 20455 | 23319 | 12599 | 25980 | 24611 | 21983 | 25980 | 23319 |

*Continuation Master Data Chart (Edge) – Social Measures*

| | | | EDGE | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Name** | **Description** | **Value Type** | **1X System Fragmentation (75% Noise)** | **2X System Fragmentation (75% Noise)** | **3X System Fragmentation (75% Noise)** | **0% Noise** | **50% Noise** | **66% Noise** | **75% Noise** | **1X System Fragmentation + 50% Noise Best Cast** | **3X System Fragmentation + 75% Noise Worst Case** |
| **Social Measurements** | | | | | | | | | | | |
| Interactions activity (mean value) | Mean value of interaction activities (i.e., number of shared, posts and pulls) per subjects | Number | 98.928571 | 179.14286 | 282.857143 | 227.89286 | 116.1428571 | 108.9642857 | 99.67857143 | 116.1428571 | 282.8571429 |
| Team inward-outward ratio | The ratio of inter and intra team interactions (i.e., shares) divided by total number of interactions. | Number [0..1] | 0.29419 | 0.2240528 | 0.19537716 | 0.1810461 | 0.322709777 | 0.313193288 | 0.293681481 | 0.322709777 | 0.19537716 |

*Continuation Master Data Chart (Edge) – Informational Measures*

| | | | EDGE | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Name | Description | Value Type | 1X System Fragmentation (75% Noise) | 2X System Fragmentation (75% Noise) | 3X System Fragmentation (75% Noise) | 0% Noise | 50% Noise | 66% Noise | 75% Noise | 1X System Fragmentation + 50% Noise Best Cast | 3X System Fragmentation + 75% Noise Worst Case |
| **Informational Measurements** | | | | | | | | | | | |
| Relevant facts accessible | Number of K/E/S factoids accessible to organization | [0..#KES factoids] | 79 | 79 | 79 | 48 | 79 | 79 | 79 | 79 | 79 |
| Facts accessible (number of) | Number of factoids accessible to organization | [0..#factoids] | 189 | 189 | 189 | 48 | 188 | 189 | 189 | 188 | 189 |
| Quality of ID 50% throught event by CCO | Quality of Interactions, Self-Synchronization, Mission Effectiveness and Mission Efficiency (given Effectiveness) (Manso and Nunes 2007) (McEver, Hayes and Martin 2007) (Martin and McEver 2008). | Precentage % | 75.00% | 50% | 75.00% | 83% | 75.00% | 50% | 50% | 75.00% | 75.00% |
| Quality of ID at the end of the event by CCO | Quality of Interactions, Self-Synchronization, Mission Effectiveness and Mission Efficiency (given Effectiveness) (References the same as above). | Precentage % | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% |
| Quality of ID 50 % throught event by JFACC | Quality of Interactions, Self-Synchronization, Mission Effectiveness and Mission Efficiency (given Effectiveness) (References the same as above). | Precentage % | 0.75% | 50% | 0.75% | 83% | 0.75% | 50% | 0.75% | 0.75% | 0.75% |

*Continuation Master Data Chart (Edge) – Informational Measures*

| | | | EDGE | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Name | Description | Value Type | 1X System Fragmentation (75% Noise) | 2X System Fragmentation (75% Noise) | 3X System Fragmentation (75% Noise) | 0% Noise | 50% Noise | 66% Noise | 75% Noise | 1X System Fragmentation + 50% Noise Best Cast | 3X System Fragmentation + 75% Noise Worst Case |
| **Informational Measurements** | | | | | | | | | | | |
| Quality of ID at the end of the event by JFACC | Quality of Interactions, Self-Synchronization, Mission Effectiveness and Mission Efficiency (given Effectiveness) (References the same as above). | Precentage % | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% |
| Quality of ID 50 % throught event by JFC | Quality of Interactions, Self-Synchronization, Mission Effectiveness and Mission Efficiency (given Effectiveness) (References the same as above). | Precentage % | 50.00% | 50% | 75% | 83% | 50% | 75% | 50% | 50.00% | 75.00% |
| Quality of ID at the end of the event by JFC | Quality of Interactions, Self-Synchronization, Mission Effectiveness and Mission Efficiency (given Effectiveness) (References the same as above). | Precentage % | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% |

*Continuation Master Data Chart (Edge) – Shared Awareness Critical Measures*

| | | | EDGE | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Name | Description | Value Type | 1X System Fragmentation (75% Noise) | 2X System Fragmentation (75% Noise) | 3X System Fragmentation (75% Noise) | 0% Noise | 50% Noise | 66% Noise | 75% Noise | 1X System Fragmentation + 50% Noise Best Cast | 3X System Fragmentation + 75% Noise Worst Case |
| **Shared Awareness Critical Measurements** | | | | | | | | | | | |
| Number of Partially Correct IDs | Number of partially correct identifications provided by subjects | [0..4 * nbrSubjects (ID-Metrics Details) | 27.5 | 27.5 | 27.5 | 27.5 | 27.5 | 27.5 | 27.5 | 27.5 | 27.5 |
| Time of First Correct ID | The time to first correct and complete identification by any participant. | Number (ID-Metrics Details) | 661.877 | 637.832 | 637.832 | 637.832 | 637.832 | 637.832 | 637.832 | 637.832 | 637.832 |
| CSSync (Cognitive Self-Synchronization) 50% throught the Event | Cognitive self-synchronization value (Marco and Moffat 2011). | Number [0..1] | 0.82 | 0.82 | 0.82 | 0.98 | 0.82 | 0.82 | 0.83 | 0.82 | 0.82 |
| CSSync Uncertainty 50% throught Event | Uncertainty measurement associated with CSSync (Marco and Moffat 2011). | Number [0..1] | 0.16 | 0.16 | 0.16 | 0.00 | 0.16 | 0.16 | 0.61 | 0.16 | 0.16 |
| CSSync (Cognitive Self-Synchronization) | Cognitive self-synchronization value (Marco and Moffat 2011). | Number [0..1] | 0.98 | 0.99 | 0.99 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.99 |
| CSSync Uncertainty | Uncertainty measurement associated with CSSync (Marco and Moffat 2011). | Number [0..1] | 0.00 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |

*Table 20.* Master Data Chart (Nominal) – General Measures

| General Measurements | | | NONIMAL | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Name | Description | Value Type | 1X System Fragmentation (75% Noise) | 2X System Fragmentation (75% Noise) | 3X System Fragmentation (75% Noise) | 0% Noise | 50% Noise | 66% Noise | 75% Noise | 1X System Fragmentation + 50% Noise Best Case | 3X System Fragmentation + 75% Noise Worst Case |
| Duration | Duration of a run (in agent's time, measured in Minutes) | Number (Run-Info) | 18m 4.363 | 18m 12.50 | 18m 5.322 | 18m 1.23s | 18m 3.010 | 18m 9.507 | 18m 5.175 | 18m 3.010 | 18m 5.322 |
| Compression factor | Compression of time used to accelerate agent runs (e.g., 0.1 means 1 minute in agents time is 10 minutes in human's time) | Number (Run-Config) | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| Total Shares | Number of shares performed by all members | Number (Event -Summary) | 4349 | 2714 | 2703 | 1726 | 5971 | 5403 | 4349 | 5971 | 2703 |
| Total Posts | Number of posts performed by all members | Number (Event -Summary) | 267 | 184 | 258 | 63 | 265 | 267 | 267 | 265 | 258 |
| Total Pulls | Number of pulls performed by all members | Number (Event -Summary) | 2966 | 8196 | 11758 | 6450 | 3365 | 3179 | 2934 | 3365 | 11758 |
| Total IDs | Number of IDs performed by all members | Number (Event -Summary) | 194 | 182 | 182 | 183 | 186 | 194 | 189 | 186 | 182 |
| List of Sense Making agent files | Filename of agents file configuration | Text (Run-Config) | | | | | | | | | |
| Workload | Measured as the number of actions requiring information processing work, that is, number of share received actions, pull actions and direct distributions | Number (Event-Summary-Total) (all columns except First Post) | 19477 | 19587 | 23978 | 11818 | 22504 | 21482 | 19739 | 22504 | 23978 |

*Continuation Master Data Chart (Nominal) – Social Measures*

| | | | NONIMAL | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Name** | **Description** | **Value Type** | **1X System Fragmentation (75% Noise)** | **2X System Fragmentation (75% Noise)** | **3X System Fragmentation (75% Noise)** | **0% Noise** | **50% Noise** | **66% Noise** | **75% Noise** | **1X System Fragmentation + 50% Noise Best Case** | **3X System Fragmentation + 75% Noise Worst Case** |
| **Social Measurements** | | | | | | | | | | | |
| Interactions activity (mean value) | Mean value of interaction activities (i.e., number of shared, posts and pulls) per subjects | Number | 115.4643 | 299.2857 | 429.1429 | 232.6071 | 129.6429 | 123.0714 | 114.3214 | 129.6429 | 429.1429 |
| Team inward-outward ratio | The ratio of inter and intra team interactions (i.e., shares) divided by total number of interactions. | Number [0..1] | 0.223289 | 0.138561 | 0.112728 | 0.146048 | 0.265331 | 0.251513 | 0.220325 | 0.265331 | 0.112728 |

*Continuation Master Data Chart (Nominal) – Informational Measures*

| | | | NONIMAL | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Name | Description | Value Type | 1X System Fragmentation (75% Noise) | 2X System Fragmentation (75% Noise) | 3X System Fragmentation (75% Noise) | 0% Noise | 50% Noise | 66% Noise | 75% Noise | 1X System Fragmentation + 50% Noise Best Case | 3X System Fragmentation + 75% Noise Worst Case |
| **Informational Measurements** | | | | | | | | | | | |
| Relevant facts accessible | Number of K/E/S factoids accessible to organization | [0..#KES factoids] | 79 | 79 | 79 | 48 | 79 | 79 | 79 | 79 | 79 |
| Facts accessible (number of) | Number of factoids accessible to organization | [0..#factoids] | 189 | 189 | 189 | 48 | 189 | 189 | 189 | 189 | 189 |
| Quality of ID 50% throught event by CCO | Quality of Interactions, Self-Synchronization, Mission Effectiveness and Mission Efficiency (given Effectiveness) (Manso and Nunes 2007) (McEver, Hayes and Martin 2007) (Martin and McEver 2008). | Precentage % | 50% | 50% | 50% | 83% | 50% | 50% | 50% | 50.00% | 50.00% |
| Quality of ID at the end of the event by CCO | Quality of Interactions, Self-Synchronization, Mission Effectiveness and Mission Efficiency (given Effectiveness) (References the same as above). | Precentage % | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% |
| Quality of ID 50 % throught event by JFACC | Quality of Interactions, Self-Synchronization, Mission Effectiveness and Mission Efficiency (given Effectiveness) (References the same as above). | Precentage % | 50% | 50% | 75% | 83% | 75% | 75% | 75% | 75.00% | 75.00% |

*Continuation Master Data Chart (Nominal) – Informational Measures*

| | | | NONIMAL | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Name | Description | Value Type | 1X System Fragmentation (75% Noise) | 2X System Fragmentation (75% Noise) | 3X System Fragmentation (75% Noise) | 0% Noise | 50% Noise | 66% Noise | 75% Noise | 1X System Fragmentation + 50% Noise Best Case | 3X System Fragmentation + 75% Noise Worst Case |
| **Informational Measurements** | | | | | | | | | | | |
| Quality of ID at the end of the event by JFACC | Quality of Interactions, Self-Synchronization, Mission Effectiveness and Mission Efficiency (given Effectiveness) (References the same as above). | Precentage % | 100.00% | 83.00% | 83.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 83.00% |
| Quality of ID 50 % throught event by JFC | Quality of Interactions, Self-Synchronization, Mission Effectiveness and Mission Efficiency (given Effectiveness) (References the same as above). | Precentage % | 50% | 50% | 50% | 83% | 50% | 50% | 50% | 50.00% | 50.00% |
| Quality of ID at the end of the event by JFC | Quality of Interactions, Self-Synchronization, Mission Effectiveness and Mission Efficiency (given Effectiveness) (References the same as above). | Precentage % | 100.00% | 83.00% | 83.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 83.00% |

*Continuation Master Data Chart (Nominal) – Shared Awareness Critical Measures*

| | | | NONIMAL | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Name** | **Description** | **Value Type** | **1X System Fragmentation (75% Noise)** | **2X System Fragmentation (75% Noise)** | **3X System Fragmentation (75% Noise)** | **0% Noise** | **50% Noise** | **66% Noise** | **75% Noise** | **1X System Fragmentation + 50% Noise Best Case** | **3X System Fragmentation + 75% Noise Worst Case** |
| **Shared Awareness Critical Measurements** | | | | | | | | | | | |
| Number of Partially Correct IDs | Number of partially correct identifications provided by subjects | [0..4 * nbrSubjects (ID-Metrics Details) | 27.5 | 24.75 | 24.75 | 27.5 | 27.5 | 27.5 | 27.5 | 27.5 | 24.75 |
| Time of First Correct ID | The time to first correct and complete identification by any participant. | Number (ID-Metrics Details) | 568.974 | 538.578 | 509.815 | 637.832 | 637.832 | 637.832 | 637.832 | 637.832 | 509.815 |
| CSSync (Cognitive Self-Synchronization) 50% throught the Event | Cognitive self-synchronization value (Marco and Moffat 2011). | Number [0..1] | 0.82 | 0.78 | 0.77 | 0.91 | 0.76 | 0.78 | 0.76 | 0.76 | 0.77 |
| CSSync Uncertainty 50% throught Event | Uncertainty measurement associated with CSSync (Marco and Moffat 2011). | Number [0..1] | 0.16 | 0.16 | 0.16 | 0.05 | 0.16 | 0.16 | 0.16 | 0.16 | 0.16 |
| CSSync (Cognitive Self-Synchronization) | Cognitive self-synchronization value (Marco and Moffat 2011). | Number [0..1] | 0.98 | 0.95 | 0.95 | 0.98 | 0.98 | 0.98 | 0.98 | 0.98 | 0.95 |
| CSSync Uncertainty | Uncertainty measurement associated with CSSync (Marco and Moffat 2011). | Number [0..1] | 0.00 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |

# CHAPTER FIVE – CONCLUSIONS, IMPLICATIONS, AND FUTURE RESEARCH

This dissertation is a Case Study using Critical System Thinking (CST) to address the following hypothesis: is there a recognizable (and discoverable) relationship between the social (human) network and technical supporting network? Other researchers perceive there is a relationship between the technical network and the human network in Command and Control. Cliff Joslyn and Luis M. Rocha write:

Our world is becoming an interlocking collective of *Socio-Technical Organizations (STOs)*: large numbers of groups of people hyperlinked by information channels and interacting with computer systems, and which themselves interact with a variety of physical systems in order to maintain them under conditions of good control. Primary examples of STOs include Command and Control Organizations (CCOs) such as 911/Emergency Response Systems (911/ERS) and military organizations, as well as utility infrastructures such as power grids, gas pipelines, and the Internet. The architecture of such systems is shown in Fig. 1, where a physical system is controlled by a computer-based information network, which in turn interacts with a hierarchically structured organization of semiotic agents.

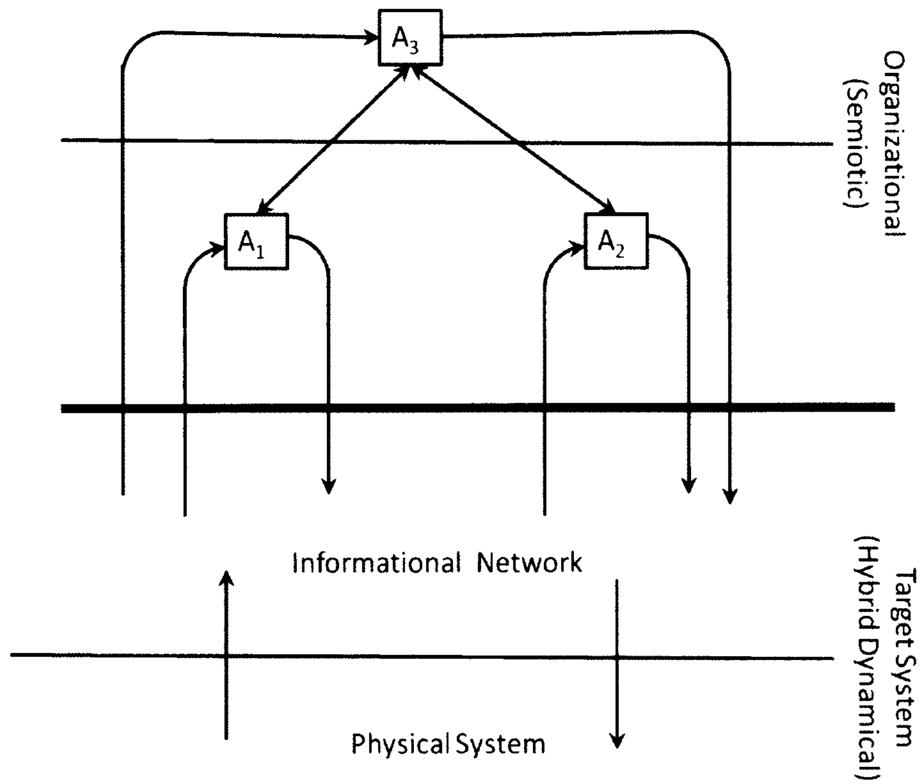



*Figure 70.* The architecture of STOs (Modification of Joslyn & Rocha, 2000)

The potential impacts on planetary economy and ecology are just beginning to be understood.

The vast complexity and quantity of information involved in these systems makes simulation approaches necessary, and yet the existing formalisms available for simulation are not sufficient to reflect their full characteristics. (Joslyn and Rocha, 2000)

We can begin to understand the relationship between the human network and the technical network by examining the system under change. Changes in the technical network should result in changes in the social network, and changes in the social network should result in a measurable difference in utilization of the technical network. This paper has demonstrated that what I posit is valid. Using a quantitative method supplied by ELICIT, I have demonstrated that the tenets of Network Centric Warfare (NCW) are bound. Contingency theory states that there is no best way to organize; not all ways to organize are equally effective. Knowing NCW is bound, and as we move deeper into the Information Age, we need to understand Air Power C2 from a scientific approach to maximize its utility.

**5.1 CONCLUSIONS**

The purpose of this research is to conduct an analysis of a representative Air Power Operational C2 node using a case study design to elicit fundamental understanding. I have achieved this purpose. The primary research question was to determine how a representative AOC C2 system changes, varying noise and system fragmentation, when in either a Nominal or Edge organizational construct. In some ways (overall early cognitive self-synchronization), the results show Nominal as the better performing organization, though in other ways, Edge (no loss of cognitive self-synchronization over the entire event) is better. The analysis provides understanding that the AOC is a socio-technical system of systems, and simple solutions, such as providing more data, may not support better decision-making, which could lead to better outcomes. My linked research question was to determine whether critical systems thinking could apply to military Command and Control. It can; CST creates an environment for debate, is complementary between various system approaches, and encourages pluralism.

My second research question was to determine whether NCW is unbound. I have found that NCW is bound. Moving an organization to an extreme version of Edge did not make all measures better. NCW is a robust theory, but by itself, it does not define how to make any macro organization/system perform better from an a priori perspective.

### 5.1.1 ELICIT

I modified the ELICIT C2 model to conduct this work. The data produced were extensive and required a previously developed analysis tool and a new analysis tool, custom built, to accomplish data extraction. Both C2 analysis tools work, but there are no manuals for their use; with the micro academic C2 community supporting the analysis tools, they are best defined as 'clunky.' Although the ELICIT model has been validated against humans, the analysis tools have not been validated. C2 modeling to understand complex systems provides one more arrow in the quiver to evaluate operational C2 as compared to actual warfare, historical studies, field experiments, or just buying more, faster, and 'better' sensors and communication gear. ELICIT was vital to this work. As an academic tool made available to all, with the only caveat being the output, it shows its proclivity for emancipation or improvement of the C2 community.

### 5.1.2 Move towards System of Systems Engineering (SoSE)

Powerful and dynamic forces are increasingly relevant to today's military C2 environment. The advent of ubiquitous worldwide communications is increasing the rate at which knowledge grows, and is shaping how it flows through our systems. The inexorable progress of technological innovation creates possibilities as it destroys established processes and augments current knowledge. Traditional systems engineering pursues creation of an isomorphic engineering model. In today's dynamic environment, new C2 problems are emerging that resist isomorphic modeling. Traditional systems engineering approaches are not sufficient. SoSE extends that systemic perspective to find solutions for the problems that systems of systems create (Kern, 2006). SoSE requires the use of Minimum Critical Specifications (Taylor & Felten, 1996), which stipulates only essential constraints to achieve overall performance level required by a system. Excessively specific documents limit flexibility in the operation and the system. Minimal specificity permits integration of the system to produce consistent levels of performance. The methodology in documentation supports a federation of systems in which no central authority provides direction and autonomy; thus, heterogeneity and distribution hold the organization in place through participation, cooperation and collaboration (Krygiel, 1999).

Another principle of SoSE is content analysis. Strength of SoSE vice traditional systems engineering is use of context analysis to address problems with a high degree of contextual influence. The theory of context concerns "relevant circumstances, factors, conditions, and patterns that both constrain and enable the system solution development, deployment, operation, and transformation" (Keating et. al, 2003). Methodology that addresses successful context analysis includes a process for continual evaluation of how context affects analysis, design, and transformation. In SoSE theory, one may expect that failure to adequately account for context will show a strategic failure of some type for the system (Keating et. al, 2004). One C2 structure does not fit every C2 problem. Only by understanding the C2 structure within a given context can one improve the issue. Moving all toward edge or any other change should be understood within the larger context.

A third SoSE principle is Boundary Establishment and Control. "A boundary separates a system and its environment. Defining a boundary is tantamount to defining the thing that is to be considered as a 'system' and those other things that are to be considered as the system's 'environment" (Leonard & Clemson, 1984). SoSE recognizes the problem inherent in establishing boundaries and acknowledges that boundaries change over time. In the documentation, boundary changes should be processed and potential impact mitigated. The AOC does not have to consist of hardware and people in one fixed location. We self-limit when we define it in those terms.

A salient factor of SoSE is iteration. Iteration in complex systems is recognizing a process that evolves with additional information and understanding of the system and the environment in which it operates. Failure to iterate a problematic system solution assumes perfect initial determination of the system – an unworthy assumption for any complex system (Gibson, 1991). Documents that incorporate iteration assume a changing environment with shifts in condition and requirements. Iteration should be a continuous reevaluation process with many parallel loops (Bahill et.al, 2002). As the AOC moves forward in time there is not one optimal solution; there is a solution for today and a solution for tomorrow.

This paper attempts to provide additional information and understanding of the 'problem.'

SoSE recognizes Complementary Law, in which any two perspectives will reveal truths regarding that system that are neither entirely independent nor entirely compatible (Basic Ideas of General System Theory, 1936). Complementary law includes multiple views and perspectives, particularly in the formative stage of a SoS effort, to ensure a robust approach and design. Failure to include multiple perspectives is recognizably limiting to the eventual solution (Clemson, 1984). Using CST to observe the AOC from both a technical perspective and social perspective incorporates Complementary Law.

A sixth recognized aspect of SoSE is transformation. Only through actual transformation do changes occur: resources are expended, transformation objectives pursued, and results (intended and unintended) emerge. Adjustments to strategy, based on intended and unintended results achieved, must maintain the correct trajectory for transformation (Keating et. al, 2004). Simons (YEAR) agrees any system must plan for moves from stable form to stable form. Complex systems will develop and evolve within an overall architecture much more rapidly if there are stable intermediate forms (Simons, 1969). Methods that should be detected in user documents include a process to encourage readjustment to both intended and unintended results as the SoS moves from one stable form to another. It is not expected to move from a starting point today to some future ending point without a process to vector the effort continually with planned stable intermediate points.

A seventh principle of SoSE is self-organization, in which complex systems tend to organize themselves, and characteristic structural and behavioral patterns result from interaction among system parts. Self-organizing reinforces the homeostasis principle wherein systems survive only as long as all essential variables are maintained within their physiological limits (Clemson, 1984). Maximizing autonomy (freedom of action and decision) within minimal system level constraints achieves this status. Constraints are limited to those necessary for system integration.

An eighth principle is System Control. In management structure, the potential to act effectively belongs to that subset of management that first acquires proper information. Information confers power. Any situation can potentially be resolved in numerous ways by numerous subsets of the manager. Failure to recognize this potential (or overzealous adherence to chain of command) robs an organization of creative solutions, ability to recognize crucial facts, trends, and events, and a large fraction of its overall decision-making capability. Redundancy of potential command increases speed of response, ability to detect novel events, information, trends, threats, and opportunities, creativity and decision-making, and comprehensiveness of decision-making (Leonard & Clemson, 1984). Assessing expected information flow in requirements generation, according to the International Council on System Engineering, does not occur in a vacuum. An essential part of requirements development is the operations concept, the implicit design concept that accompanies it, and associated technology demands. System needs cannot be established without checking impact (achievability) on lower level elements. Information flow and system control is a 'top-down' and 'bottom-up' iteration and balancing process. "Control for a System of Systems is achieved by maximizing the autonomy of subsystems. The SoSE methodology must appreciate target designs that provide for the highest levels of subsystem autonomy. Control is achieved by establishment of subsystem performance expectations that maximize overall system of systems performance" (Keating et. al, 2004).

The ninth principle is rigorous analysis. According to Keating, et al. (2004), the SoSE methodology is intended to provoke rigorous analysis resulting in the potential for alternative decision, action, and interpretations for evolving complex system of systems solutions. The SoSE methodology analyzes and frames problems and their context, manages emergent conditions, and takes decisive action. The methodology provokes higher levels of inquiry, systemic analysis, and advanced understanding of seemingly intractable problems en route to robust solutions (Keating et al., 2004).

Rigorous analysis does not rely on simple 'cut and paste' or standard 'cookie cutter' approaches to problem solving. The underlying philosophical approach applies core concepts from General System Theory.

The tenth standard and final subset is system outcome achievement. According to Keating (2004), another principle of SoSE is the ability to produce desirable results,

Metasystem performance must ultimately be judged on whether or not it continues to meet expectations for positive impact on the problematic situation or continued fulfillment of an identified need/mission. A problem for SoSE is the concern for shifting expectations of stakeholders that may change fluidly throughout the life of the system of systems (Keating et al., 2004).

Measures of performance must be established carefully to allow SoSE to focus on output measurement as well as outcome. By incorporating SoSE principles into designing my AOC, I have an opportunity to move far past the marketing phrase, 'right information, at the right time, in the right place, in the right format,' to an engineering solution that actually has the potential to improve overall capability.

## 5.2 IMPLICATIONS

Every research project has an implied or a specified strategy. The strategy needs to match the intellectual goal. The intellectual question that requires resolution is always: 'What will be achieved at the end of the research process?' See Appendix A for a complete breakdown of the analysis of this work. Quantitative research is designed to help people make sense of what is going on in the world around them (Easterby-Smith et al., 2002). Case study work offers the ontological assumption that the aim of the study is to represent various views of multiple realities. The literature review indicates the C2 universe is diverse. Every nation state thinks about C2. Every service practices C2 differently. I hope that what I achieve at the end of the research process is to provide some clarity on the future of C2 research.

I have employed the following strategies to mitigate potential criticisms to this scholarly research. The various thought camps (hard science vs. soft science) are not two stovepipes of either/or; they are bookend arguments of the scientific process. Buhari (2010) captured this continuum very well in the following chart:

Network of basic assumptions characterizing the subject-objective debate within social science

| | **Subjective Approaches to Social Science** | | | | | **Objective Approaches to Social Science** |
|---|---|---|---|---|---|---|
| **Core Ontological assumptions** | Reality as a project of human imagination | Reality as a social construction | Reality as a realm of symbolic discourse | Reality as a contextual field of information | Reality as a concrete process | Reality as a concrete structure |
| **Assumptions About Human Nature** | Man as pure spirit, consciousness being | Man as social construction the symbol creator | Man as an actor the symbol user | Man as an information processor | Man as adaptor | Man as responder |
| **Basic Epistemological Stance** | To obtain phenomenological insight, revelation | To understand how social reality is created | To understand patterns of symbolic discourse | To map context | To study systems, process, change | To construct a cositivist science |
| **Some Favored Metaphors** | Transcendental | Language game, accomplishment, test | Theater, culture | Cybernetic | organism | Machine |
| **Research Method** | Exploration of pure subjectivity | hermeneutics | Symbolic analysis | Contextual analysts of Gestalten | Historical analysis | Lab experiment, survey |

*Figure 71.* Network of Basic Assumptions (Adapted from Morgan and Smircish,1980)

Understanding the bookend arguments, the conversation quickly moves back to defining what science is. A classic scientific research approach implies qualitative research being the prerequisite to accomplish quantitative evaluation. Look at how Newton worked and how he applied the scientific approach: he used his senses to see the apple fall from the tree. Through *inductive* reasoning, he was able to formulate that two objects attract each other (*empiricism*). His reasoning was a qualitative finding. Only after the reasoning did he gather the data and conduct experiments to test his expectations/hypothesis. Through his use of both qualitative and quantitative methods, he was able to produce the Universal Law of Gravitation.

Myers' (2000) argument is not to address the 'weakness,' but to quantify the strengths of qualitative research:

A major strength of the qualitative approach is the depth to which explorations are conducted and descriptions are written, usually resulting in sufficient details for the reader to grasp the idiosyncrasies of the situation. (Myers, 2000)

By moving the point of reference, simple defense can quickly become active defense. This research is qualitative; one goal of this research is only to set the stage for further research into understanding of the fundamentals of Air Power C2.

## 5.3 FUTURE RESEARCH RECOMMENDATIONS

Command and Control systems for Air Power will most likely remain warfighters using systems to artificially represent reality, and respond to and influence that reality. Airpower will provide a critical umbrella of global reach and global strike for most military operations. It should be expected that something like Air Tasking Order will be the mechanism that is used for self-synchronization and synchronization with other components. Future research needs to address three C2 subjects utilizing a scientific process. The first research that needs to be undertaken is to determine the underlying non-changing principles of Air Power C2. The second area of research is to understand how C2 can be employed as an offensive weapon. Third, we must ask how we can maximize the effectiveness and efficiency of the macro C2 socio-technical system in an information-saturated milieu.

### 5.3.1 Philosophical Issues

Theoretical paradigm has been defined as "a loose collection of logically held together assumptions, concepts, and propositions that orientates thinking and research" (Bogdan & Biklan, 1982), or it could be defined as a "basic belief system or world view that guides the investigation" (Guba & Lincoln, 1994).

Positivism defines natural and social sciences as measureable autonomous facts within the realm of individual perception of reality (Gabriel, 1990). Therefore, reality is composed of discrete elements that can be recognized and classified (Guba & Lincoln, 1994; Hirschman, 1986, Tsoukas, 1989). Research based on positivism is theory-testing based on deduction (Layder, 1993).

If a researcher does not fall totally into the positivism camp, the other epistemological orientation is interpretivism (anti-positivism), which broadly defines, "any kind of research that produces findings not arrived at by means of statistical procedures or other means of quantification" (Strauss & Corbin, 1990).

*Table 21.* Basic belief systems of alternate inquiry paradigms

| Item | Positivism | Critical Theory | Constructivism | Realism |
|---|---|---|---|---|
| *Ontology* | *Naïve Realism*: reality is 'real' and apprehensible | *Historical Realism*: 'virtual' reality shaped by social economic, ethnic political, cultural and gender values, crystallized over time | *Critical Relativism*: multiple local and specific 'constructed' realities | *Critical Realism*: reality is 'real' but only imperfectly and probabilistica lly apprehensible and so triangulation from many sources is required to know it |
| *Epistemology* | *Objectivist*: findings true | *Subjectivist*: value mediated findings | *Subjectivist*: findings created | *Modified Objectivist*: findings probably true with awareness of values between them |
| *Common Methodologies* | *Experiments/ Surveys*: verification of hypothesis; chiefly quantitative methods | *Dialogic/ Dialectical*: researcher is a transformative intellectual' who changes the social world within which participants live | *Hermeneutical/ dialectical*: researcher is a 'passionate participant' with the world being investigated | *Case Sudies/ Convergent Interviewing*: triangulation, interpretation of research issues by qualitative and/or quantitative methods (such as structural modeling) |

Case studies [like this one] have unjustifiably acquired a reputation for being semi-anecdotal investigation of the small details of individual circumstances, research that is incapable of generating significant empirical or theoretical advances in knowledge (Leo, 2008, p. 2).The two philosophies that form the basis of a majority of research are quantitative and qualitative (Creswell, 2003). Those philosophies can be associated with other terms and concepts:

- Positivism (quantitative) is a concept that has a strong relationship to empiricism, nominalism, and mathematics.
- Naturalism (qualitative) is an argument that relates to contextualism and symbolic interrelationism.

Both philosophies tend to be associated with pragmatic thought, and reject idealism and realism.

This Case Study uses naturalism as its scientific method as it is a pragmatic way to approach so complicated a subject as Air Power C2.

**5.3.2 Theoretical Issues**

The future of C2 in the Information Age is a conundrum. How the antagonists of some future war organize, equip, and train has not been set in theoretical "stone." Confusion begins with no common lexicon on exactly what is meant by the simple terms 'command' and 'control.' Will information continue to grow into a bane or will it become another offensive weapon available for exploitation? Theory like Network Centric Warfare is being developed and tested. In some ways, C2 theory does not always have a recognizable 'off ramp' to reach the field practitioner.

**5.3.3 Axiological Issues**

The value of repeatable C2 case study research should be judged against the canon of science and ethics for viability, as it is not historical in nature nor should C2 be 'experimented' within the heat of battle. I have evaluated this dissertation against the four canons of science for viability and the results are:

1) Determinism- assumes the universe is orderly. All events have causes. The hypothesis is deterministic, as it assumes there is a connection between the human domain and the technical domain providing the abstraction of reality for the warfighters.
2) Empiricism- The best way to determine the orderly principles of the world is to observe carefully. This dissertation carefully takes a subset of facts and conditions and evaluates them in detail utilizing Critical System Thinking, observing both pro and counter arguments.
3) Parsimony- When two competing theories are equal in explaining empirical observations, one should choose the simpler, or more parsimonious, of the two. We should be careful in developing any new theories. Network Centric Warfare has been observed as to whether it 'fits' all conditions.
4) Testability- This is the assumption that any scientific theories should be testable. Testing in combat is not viable across a theater scale; a human validated model has accomplished testing.

From ethics, canons can lead to ethical considerations of the research. For evaluation in this framework, I will consider five ethics: Utilitarian, Rights, Fairness or Justice, Common Good, and Virtue:

1) A utilitarian approach provides the most good or does the least harm, as it balances good over harm. Using a human viable mode (ELICIT) does not harm humans nor force organizations either to reorganize or to be equipped with costly new kits.
2) A rights approach uses a common set of rights that all should have. Such rights include the right to make one's own choices in life, the right to be told the truth, the right not to be injured, and the right to some degree of privacy. This research is not funded by any organization and is accomplished purely to understand fundamental C2 issues.
3) Fairness or Justice is the concept that all should be treated equally. Let the ideas in this paper stand on their own merit. It is searching for 'truth,' and only the validity of the argument and time should judge the final results.
4) Common Good is an approach that suggests relationships between society and a compassion for others, especially the vulnerable. This approach also calls for common conditions to be set for the welfare of everyone.

5) A common list of virtues are honesty, courage, compassion, generosity, tolerance, love, fidelity, integrity, fairness, self-control, and prudence.

Researching C2 using a model based case study is a viable axiological technique.

**5.3.4 Methodological Issues**

There is little literature available that validates capturing data to support building a thematic lens to provide elicitation on Command and Control. What I present is that there is a recognizable (and discoverable) relationship between the social network and technical network. Understanding of that relationship can begin by examining the system under change using a repeatable method. Changes in the technical network will result in changes in the social network, and changes in the social network will result in a measurable difference in utilization of the technical network. The literature review, not being historical in nature, opens itself up to scrutiny in that the results may not support the overarching research concept. By selecting Critical System Thinking (CST) as an inquiring process, I have accomplished a relevant literature search, and the results can be interwoven into any emerging C2 theory. Data can be 'cherry picked,' and ELICIT and the ELICIT analysis tools are predefined. To insure viability, criteria used for comparison was developed and refined by Marco Manso in his 2012 paper, "N2C2M2 Validation using abELICIT: Design and Analysis of ELICIT runs using software agents" presented at the 17th ICCRTS. The reliability of this study is based on following a recognized Case Study research method. An in-depth self-analysis of this paper is available in Appendix A.

If I have learned anything about Air Power C2, I have learned I *know* very little. I am trying to accomplish some fundamental understanding. The C2 model I am using was provided pro-bono and I had to work within the constraints of the model. The only way to address the concerns of qualitative research is to follow a well-known model like case study using CST as an inquiry method. In many ways, qualitative research has been fighting 'uphill' against quantitative research for centuries. To address the issue of qualitative validation in this dissertation, I pulled reasoning for the paper by starting at the philosophy, driving it into the epistemology, and continuing into the ontology. Using this methodology, one can assume CST in a single case study to be a valid approach. Additionally, some may point to the lack of quantitative support in the work and the ELICIT model not being robustly realistic. In response, I should point to Macy:

Analysis of very simple and unrealistic models can reveal new theoretical ideas that have broad applicability, beyond the stylized models that produced them. Pressure to make models more realistic (and agents more cognitively sophisticated) is misguided if models become so complex that they are as difficult to interpret as natural phenomena. When researchers must resort to higher order statistical methods to tease apart the underlying causal processes, the value of simulation is largely undermined (2002).

**5.3.5 Practical Issues**

In his study of airpower in the first Gulf War, James Coyne (1992) notes:

> Before the age of electronics and aerospace technology, command and control—in the modern sense of the term—was a comparatively minor element in warfare. Battles were fought, albeit inefficiently and often

> ineffectively, independent of the health of supporting communications. (p. x)

This paper using CST (Critical System Thinking) has attempted to uncover fundamental concepts of C2 as they relate to the execution Air Power. Two organizational constructs were identified (Nominal and Edge). George Orr (1983) uses the term hierarchical organization vise Nominal organization, but the thought is same; it is as an organization that:

> attempts to turn the entire military force into an extension of the commander. Subordinate levels respond in precise and standardized ways to his orders and provide him with the data necessary to control the entire military apparatus. The emphasis is upon connectivity hierarchy, upon global information gathering or upon passing locally obtained information to higher levels, and upon centralized management of the global battle. (p. 109).

At the other end of the spectrum is an Edge organization. In 1983, Orr used the term network vise Edge, but again the underlying concept is the same. Orr (1983) describes his network/edge concept these terms:

> views the commander as controlling only in the sense of directing a cooperative problem solving effort. The emphasis in this style is on autonomous operation at all levels, upon the development of distributed systems and architectures, upon networking to share the elements needed to detect and resolve possible conflicts, and upon distributed decision making processes. (p.110)

Just as in 1983, Edge organizations gather and process information with the goal that the information will be equally distributed and made available to all that need it with the assumption that more and rapidly-transmitted information to all levels of command will improve decision-making.

As we enter the Information Age, history has proven that organizations can be overwhelmed with their exaction of reality (information) as it is provided by their own massive technological infrastructure. The United States Navy guided missile cruiser VINCENNES shot down the 290 passengers and crew of Iran Air Flight 655 when it fired two missiles on July 3, 1988. In his 1990 book *Artificial Intelligence at War: An Analysis of the Aegis System in Combat*, Chris Gray (1990) argues that "the Aegis gave the *Vincennes*' captain and crew the illusion that they knew more than they did" (p. 126-139). Also,

> "*Aegis* [the *VINCENNES* radar system] *is a man-machine weapon system*" [italics in original]; as such, sailors must exercise a healthy skepticism about the information they are presented, rather than blindly trust the "system" of which they are unknowingly a part. (p. 126-139)

The practical issues are not just better computer design, or system design, or how to organize to use all information that can be provided effectively, or how not to be overwhelmed by information. The issue identified in this paper is to learn how to understand and discover core C2 concepts by using a quantitative repeatable approach. Van Creveld (1991) writes: "The paradox is that, though nothing is more important than unit of command, it is impossible for one man to know everything. The larger and more complex the forces that he commands, the more true this becomes" (p. 109).

One should note that Napoleon used centralized control, and commanded 85,000 men at Austerlitz with great success; however, he lost control of half his force of 150,000 men at Jena and had no control of his 180,000-man force at Leipzig (Van Creveld, 1991). John Boyd in his unpublished notes argues convincingly that Napoleon's military downfall can be attributed directly to his use of a highly centralized command and control system. Organization uncertainty (entropy) is a condition subject to the will of all Commanders. Most Commanders, just being human, will desire to drive their entropy towards zero. Van Creveld (1991) believes that while centralization reduces uncertainty (entropy) at the top, it increases that uncertainty (entropy) at the bottom. Decentralization has just the opposite effect (Snyder, 1993).

## 5.4 SUMMARY

One cannot help but look upon the social environment and the underlying technological infrastructure we are constructing for Command and Control without some trepidation. As the macro C2 system evolves, one should expect it to become more structurally complex, as history has demonstrated. Warfighters and their technology will always have a symbiotic relationship. Moving forward, this should not be a problem in and of itself. We need to recognize the mismatch between the optimism brought by science and engineering and the sometimes hidden risk of complex system behavior. In complex systems, the sum is always greater than the parts. It is well known that any deterministic system will generate random-seeming behavior given a long enough period of time.

The philosopher Alfred North Whitehead captured the essential character of evolving, adapting systems most elegantly when in the 1920s he considered the domain of human social organization:

> The social history of mankind exhibits great organizations in their alternating functions of conditions for progress, and of contrivances for stunting humanity. The history of the Mediterranean lands, and of western Europe, is the history of the blessing and the curse of political organizations, of religious organizations, of schemes of thought, of social agencies for large purposes. The moment of dominance, prayed for, worked for, sacrificed for, by generations of the noblest spirits, marks the turning point where the blessing passes into the curse. Some new principle of refreshment is required. The art of progress is to preserve order amid change, and to preserve change amid order. (Whitehead, 1927-28)

We should not sit in the intellectual darkness and hope and pray our industrial-military complex "figures out" Air Power C2. It is better to light just one candle.

In this dissertation, I have defined the unique contributions"C2 in the Information Age" brings to the plethora of C2 thought. I segregated seminal authors in both IT and Social Networking into two schools of thought. The IT school of thought concentrating on machine themes and would be made up of authors such as Shannon (1949), Ashby (1948), Beer (1985), Conant (1976), Sommerhoff (1950), Brillouin (1962), Nørretranders (1991), and Waelchli (1989). The Social Networking school of thought, that I identified as being made up of authors that are concerned with the human/organizational themes, consists of authors like Mathieu (2000), Carley (1997), Klimoski and Mohammed (1994), Sonnenwald and Pierce (1998), Kaplan (1980), Graham (2004), Barnes (1954), Hanneman (2005), Granovetter (1973), and Milgram (1967). Between these two giant schools of thought, there is a much smaller pool of authors that write about themes that bind both the machine and the human themes from a synthesis perspective. This pool consists of thinkers like Bharadwaj andKonsynski (1999), Brynjolfsson and Hitt (2000), Aral and Weill (2007), Hinds and Kiesler (2002), Cyert and March (1963), Arrow (1962), Stiglitz (2000), and Joslyn and Rocha (2000).

As Sutton (1986) points out, a common definition of C2 will most likely never congeal. Just because something does not carry a universally recognized moniker does not mean it cannot be thought about or measured, or made better. Between C2 theory and C2 operations stands C2 Systems. I refined a model to shows process sequence as well as the information flow internally processed by the operator. By describing how information is integrated and reduced in stages, the model provides initial elucidation. I used the same model to represent asymptotic performance or something less than standard without defining individual failure. The model also conveyed various flows created from constrained extraction of the theater air power open system. In the propose process, inputs are matched with the operator's tacit knowledge or mental model and transformed to another type of output. Information at this stage underwent a higher level of abstraction. If the blob of incoming information was unmatched, or is validated as irrelevant, it just 'falls on the floor' (blocked). Using this conceptual model, I took the available measures of C2 and used a physical model (ELICIT) to examine the current theory of C2 (Network Center Warfare). I found it was salable and will have challenges in execution.

At the current time, all sorts of organizations, from nuclear control centers, to AOCs, to emergency management centers, to NASA, seem to have stumbled into the need to understand core C2 principles of the information age. Over time, it will be easy to judge the winners and loser in this new realm of human activity. The loser will most likely continue to try to string systems together and complain about the results until they are swept away by the tides of time and winner will "outthink" their problems. We have started in Maykish Stage 6 and the unique contribution of this paper is to begin to sort through the Uncertain that currently exists by pushing against the walls of darkness in which mankind eternally struggles.

**World View (Recognized Limitation of the Student/Author)**

I believe my selected research method supporting this dissertation work has led to an epistemic understanding of thought and arguments in Command and Control. To understand where "the question to explore resides," one must define a personal perception of the universe. My personal perception is a recognized limitation. If I had to explain my life in one word, it would be "dichotomy." I do not always believe my own senses, but, without a cogitative alternative, I must rely on them. The social universe impacts anyone's world view in infinite ways. During the Middle Ages, "wise men" would burn witches at the stake for the sake of their souls; there are many ways to be burnt alive today, both figuratively and literally, crossing social norms. Understanding how your work affects the lives of others is essential. I am a minimalist in both writing and thinking (Occam's Razor). I like solutions that meet the criteria for success without a lot of overhead. I have never learned to type long passages of fluff. Academic work must pertain to the "real world" or it is simply grist for ink makers, paper mills, and librarians. There is nothing "wrong" with supporting the economy, but there are less narcissistic ways of accomplishing it. Pure academic research is important; one of the greatest concepts so far created by man is that of "Zero." It is likely that there are other concepts as great, still waiting to be uncovered (although, I do not think I will find any of them). Pure research strips mythology and superstition by establishing truths that withstand the test of time. It has been said: "men will work very hard not to think." My goal in Engineering Management is to think and to encourage others to think.

What are my modes of reasoning? Am I inductive or deductive? Do I favor qualitative or quantitative approaches? I am surer of what I do not want to do than what I want to do. I want to start a process and vector toward a goal best defined as somewhere other than the starting point. Inductive and deductive reasoning stem from the construct of a logical universe. I believe people often suffer "failure" when they default to the belief that the world is logical; many frustrated benevolent dictators believed the world would be "perfect" if everyone would implement their "logical" argument. Maybe the best reasoning models are political, or chaotic, or even an iambic pentameter model. I like the abduction model with inductive sequels and deductive branches for my trip into the unknown, even though an abduction model is less amenable to research (Sousa-Poza, n.d.), and this dissertation steers away from it.

I do not acquiesce to strict scientific process from theory, to hypothesis, to testing, and back to theory in a straight line vector. I take small steps, and, after a few, look around to see if the milieu is lighter or darker, then continue taking steps that increase illumination of "truth." Therefore, as the eternal skeptic and always fallible, I will follow a construct of Sun Tzu: "Know yourself and know your enemy, and in a thousand battles you will be safe." That is a good place to start this journey.

What I do surmise is whatever country, organization, or non-state actor that improves operational execution through an understanding of C2 will gain a strategic advantage. Information age warfare will be different from industrial age warfare. The difference may be as great or greater that the difference between agrarian age warfare and industrial age warfare. I have hope that more data/information can be used as a resource, and will not just become a mote in our eye. Air power and ground power have combined to win the last five wars. Command and control is the glue that holds it all together.

I know researching C2 has provided me some understanding of various subsets of issues. My hope is just to light one candle in a world that is still covered in much darkness. Then again, maybe my failure will put one more "There Monsters Be Here" on the map of C2.

I do appreciate this opportunity to "swim" in trying to understand C2. It has been a joy of discovery. I have learned how to think, and with the guidance of the many ODU professors, I have had some success. I thank you.

(Post Script: I study war no more.)

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# APPENDIX A

Table 22. APPENDIX A

| | Philosophy | | Epistemology | | | | Ontology | | |
|---|---|---|---|---|---|---|---|---|---|
| | quantitative | qualitative | Evidence | Reliability | A Priori | A Posteriori | Subjective | Objective | Relative |
| **Research** Questions | No | Yes | Yes can we build a framwork and use it | No | We don't know if a framwork can be built | No | We don't know how good the framework will be or if the results will be usable | No | No |
| **Research** Hypotheses | No | Yes the Hypotheses is implied not specified (rewrite) | relationship between the social network and technical network can begin to be understood by examining the system under change | NO | No | Yes we will only be able to validate after we accomplished the research | Yes | No | No |
| Literature Review | | Uses a Soft System Methodology | NO | Used a recognized process | NO | Evaluates a set of Literature created for a single time and space | The scale, the rating and the results were developed from the observations of a single person | NO | NO |

Continued

| | Philosophy | | Epistemology | | | | Ontology | | |
|---|---|---|---|---|---|---|---|---|---|
| | quantitative | qualitative | Evidence | Reliability | A Priori | A Posteriori | Subjective | Objective | Relative |
| **Methodology** comparative case study using a physical model | | Yes | Yes we are representing the propositions as being true | NO | NO | Yes, the data will be evulated after it is collected | NO | NO | Comparing 2 set cases against each other |
| **Research Design** data collection | Yes, all data collected is quantitative | NO | No | Yes we assume the data collection tool captures what it proposes | Yes have determine what data to collect before experimentin g | No | | Yes, only captures the data planned | |
| **Research Design** data analysis | NO | Yes observation of the data and not statical evulation of the data will be used | Yes only looking at the data | NO | NO | The cases (Nonimal and Edge) will be compaired | The data will be looked at to determine relationships | NO | NO |
| **Research Design** Data sampling considerations | No | Yes, Only sample what the model is capable of providing | No | Yes others have used the same collection methods | Yes can only sample what is available | NO | No | Data sampling is set and pre determined | NO |

Continued

| | Philosophy | | Epistemology | | | | Ontology | | |
|---|---|---|---|---|---|---|---|---|---|
| | quantitative | qualitative | Evidence | Reliability | A Priori | A Posteriori | Subjective | Objective | Relative |
| Findings | NO | YES | YES | NO | NO | YES | YES | NO | NO |
| Limitations | Yes limitations are based on the Elicit Model | No | Yes | No | Yes set by the model | No | No | Yes the model is what it is | NO |
| Delimitations | Yes the number of agents | Yes the researcher extricated the proposed structure | No | It is augured as reliable | Yes Set before running the model | NO | Yes, Controlled by the researcher | NO | NO |
| **Implications** theoretical | No | The goal it to determine some basic C2 Theory | Yes | NO | NO | Yes, looking at creating a new theory | May change or build C2 theory | NO | NO |

Continued

| | **Philosophy** | | | | **Epistemology** | | | **Ontology** | |
|---|---|---|---|---|---|---|---|---|---|
| | quantitative | qualitative | Evidence | Reliability | A Priori | A Posteriori | Subjective | Objective | Relative |
| **Implications** methodological | NO | Yes, the research may validate C2 research using a physical artifical agent model | Yes | No | Yes if we can build a valid framework it could use to look at C2 in a different way | No | Yes a new method to study operational level C2 | NO | NO |
| **Implications** practical | NO | Yes, C2 research may not be more then practical experience learned in war | Yes | NO | NO | Yes may impact the actual AOC's | May or may not effect the C2 Community | NO | NO |
| Validity | NO | Yes | Yes | NO | N | Yes, The validity of the approch will be *determined if a* framwork can be created | Validity will be accomplished acceptance | NO | NO |

Continued

**Methodology**

| | Causal Compa. | Correlation | Descriptive | Experimental | Historical | Literature | Ethnography | Phenomenolog. | Case Study | Critical System Thinking |
|---|---|---|---|---|---|---|---|---|---|---|
| Problem Formulation | The research causal-comparative research attempts to determine the cause, or reason, for existing differences in the behavior or status of groups of individuals as they under go changes in the environment | we are **not** doing Correlational Research as we are **not** holding the variables static | We have some Descriptive qualities as we are describing a representative Air Power Operational C2 node | **No** | **not** trying to compare the results to actual C2 node using historical evidence | An analysis foretells an literature review | No | No | Yes | Yes we seek discovery of new theory through the critical analysis. |
| Significance | No | Yes | Marginally there is an attempt to accurately describe basic future information that may or may not be true | No | Marginally there is an attempt to accurately describe basic future information that may or may not be true | NO | Potentially, if the group is defined as members of the AOC | No | Yes | Yes as CST seeks to involving the discovery of theory through the analysis of data, and much data could be available |
| **Research** Purpose | Yes - we are looking at 2 groups (nominal and edge) and seeing the | No | Yes we are trying to describe what is happening in our artificial | No | Not trying to compare the purpose to actual C2 node using | Yes part of the review, note impossible to prove a negative | Yes we deal with one group of semi intellegent artifical agents | no using artifical agents | Yes | yes we are looking for discovery of theory through Critical awareness |

Continued

**Methodology**

| | Causal Compa. | Correlation | Descriptive | Experimental | Historical | Literature | Ethnography | Phenomenolog. | Case Study | Grounded Thee. |
|---|---|---|---|---|---|---|---|---|---|---|
| Problem Formulation | The research causal-comparative research attempts to determine the cause, or reason, for existing differences in the behavior or status of groups of individuals as they under go changes in the environment | we are **not** doing Correlational Research as we are **not** holding the variables static | We have some Descriptive qualities as we are describing a representative Air Power Operational C2 node | **No** (no IV or DV) | **not** trying to compare the results to actual C2 node using historical evidence | An analysis foretells an literature review | No | No | Yes | Yes we seek discovery of new theory through the analysis of data. |
| Significance | No | Yes | Marginally there is an attempt to accurately describe basic future information that may or may not be true | No | Marginally there is an attempt to accurately describe basic future information that may or may not be true | NO | Potentially, if the group is defined as members of the AOC | No | Yes | Yes as GT seeks to involving the discovery of theory through the analysis of data, and much data could be available |
| **Research** Purpose | Yes - we are looking at 2 groups (nominal and edge) and seeing the | No | Yes we are trying to describe what is happening in our artificial | No | Not trying to compare the purpose to actual C2 node using | Yes part of the review, note impossible to prove a negative | Yes we deal with one group of semi intellegent artifical agents | no using artifical agents | Yes | yes we are looking for discovery of theory through the analysis of data |

Continued

| | Methodology | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Causal Compa. | Correlation | Descriptive | Experimental | Historical | Literature | Ethnography | Phenomenolog. | Case Study | Critical System Thinking |
| **Research** Questions | Yes we are trying to understand a framework and its use | Yes we are trying to use data collected to create a framework | Yes we are trying to describe a new framework | No | No | No literature was found that validates the approach | No | Yes the goal is understand the specific by creating a framework | Yes we are looking at the subject through multiple lens | Yes, we are using data to create a viable framework |
| **Research** Hypotheses | Yes there is implied there is a recognizable (and discoverable) relationship between the social network and technical network | No there are to many variables to accomplish Correlation | Yes | Yes Within the 2 different cases. The independent variable are the social connection when changing the dependent variables of noise and | NO | No | No | No | NO | NO |
| Literature Review | NO | NO | Yes it tries to provide an accurate description of observations | NO | **NO**, the Literature Review not being historical in nature open up the results to scrutiny as it many not support the research | N/A | Yes (some what) the literature reviewed was from a single conference ( a discernible group) | NO | NO | As CST stated a wide range of literature review is appropriate |

Continued

Methodology

| | Causal Compa. | Correlation | Descriptive | Experimental | Historical | Literature | Ethnography | Phenomenolog. | Case Study | Critical System Thinking |
|---|---|---|---|---|---|---|---|---|---|---|
| **Methodology** comparative case study using a physical model | Yes, trying to determine | No but will attempt of a correlation emerges | Yes | Yes used a physical model | No | NO | No | No | Yes | Yes |
| **Research Design** data collection | NO | NO | YES Enough data is being captured to explain the model | Yes | NO | Yes there is some literature about similar data being captured | No | NO | NO | Yes Data collected must support CST |
| **Research Design** data analysis | Yes | No | Yes We need to be able to understand what the data means | NO | Yes use factors other have developed | Yes (Somewhat) other researcher have use this model | NO | NO | Yes looking at 2 different cases | Yes expect theories to emerge |
| **Research Design** Data sampling considerations | NO | NO | NO | NO | NO | NO | No | NO | Yes | Yes |

Continued

| | Methodology | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Causal Compa. | Correlation | Descriptive | Experimental | Historical | Literature | Ethnography | Phenomenolog. | Case Study | Critical System Thinking |
| Findings | NO | NO | Yes the goal is to describe the result of increasing noise and system fragmentation on a C2 node | NO | NO | NO | NO | NO | YES | Yes, The findings accomplish understanding |
| Limitations | NO | NO | Incorrectly described in the proposal | NO | NO | NO | NO | NO | yes sets the context | Yes sets the universe to explore |
| Delimitations | NO | NO | Incorrectly described in the proposal | NO | NO | Yes The proposed structure is derived from other written sources | Yes the number of agents are determined by the researcher | NO | Yes | Yes conditions set to maximize differences to allow understanding |
| **Implications** theoretical | No | NO | NO | Yes provides a experimental method for Operational C2 | NO | NO | No | NO | Yes Using Case Study as a method to evaluate the Operational C2 | Yes equal commitment to the informed development of all varieties of systems approaches |

Continued

| | Methodology | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Causal Compa. | Correlation | Descriptive | Experimental | Historical | Literature | Ethnography | Phenomenolog. | Case Study | Critical System Thinking |
| **Implications** methodological | NO | NO | NO | Yes provides a method to create and evaluate dependent and independent variables | NO | NO | NO | NO | Yes encourages others to use Case Study to understand Operational C2 | Yes using Critical Awareness to examine the state of the current thought |
| **Implications** practical | NO | NO | NO | Yes provide a non human venue for study of C2 | NO | NO | NO | NO | Provides researchers another method to understand operational C2 | Yes, describes procedures which critical systems practitioners can follow |
| Validity | Yes | NO | NO | YES assumes we can use a model vise actual AOC | NO | Yes | NO | NO | YES | YES |

Continued

**Methodology**

| | Causal Compa. | Correlation | Descriptive | Experimental | Historical | Literature | Ethnography | Phenomenolog. | Case Study | Critical System Thinking |
|---|---|---|---|---|---|---|---|---|---|---|
| Reliability | No | NO | Yes is based on the researcher ability to accurcy describe the AOC | NO | NO | Yes Based on current unclassifed literature | NO | NO | YES | YES |
| Future Research | Yes | Determine statically correlation of factors | Yes, Change as the AOC Changes | Yes, reuse and develop more models | NO | Yes find Literature supporting any new theory | Yes Use an representative AOC | NO | Yes | Yes , may need more new solutions to a new environment |

Continued

| | canons of science | | | | | Ethics | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Determinism | Empiricism | Parsimony | Testability | Utilitarian | Rights | Fairness | Common goou | Virtue |
| Problem Formulation | Yes, only the inputs we inject into the model will produce an output | Yes, we are carefully observing the world we create | Yes we iterative in process and minimize creating non-needed theories | Yes, repeatability validated testability | Yes, trying to understand both good and bad as the environment changes | NA | NA | NA | NA |
| Significance | **NO** the C2 universe may not be orderly | **NO** the world of C2 may not be carefully observed in the future | **No** There may be many causes and effects that change the view of the research | **NO** There is no know way to test the signifcance of the research | N/A | N/A | N/A | Yes the research can apply to all C2 nodes and beyond | Yes the significance is the research attempts to move beyond the appearance of truth and attempts to explore truth |
| **Research** Purpose | Yes | Yes | Yes we iterative in process and minimize creating non- | Yes we found elicit fundamental understanding | N/A | N/A | N/A | N/a | seeks understanding |

Continued

| | canons of science | | | | Ethics | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Determinism | Empiricism | Parsimony | Testability | Utilitarian | Rights | Fairness | Common goou | Virtue |
| **Research** Questions | yes we assume the output data will have enough order to it to create a framework | yes we study the data in-depth | **No** our the resulting framework may be complex | Yes if the framework is not testable it will assumed to be invalided | N/A | N/A | N/A | a new Framework could have many uses | a framework that is used often has to have integrity |
| **Research** Hypotheses | Yes if we validate the hypotheses it will remain so | Yes | No we don't have a theory that describes the expected relationship | Yes failure to find a relationship will prove no relationship exits | Yes academic research failure or success has utility | N/A | N/A | N/A | Yes the goal of exploring the unknown should not default to finding success |
| Literature Review | Yes, Assumes the studying a complied group of literature is representative a massive amount of literature call itself C2 related | No the current review is not a carefully study it is a study of a single point in time | NO | Yes the same literature is able to be reviewed and ranked by others | Yes, CST deal with the kind of messy problem situations that lack a formal problem definition | N/A | N/A | N/A | Yes provides integrity by using a recognized method |

Continued

| | canons of science | | | | Ethics | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Determinism | Empiricism | Parsimony | Testability | Utilitarian | Rights | Fairness | Common good | Virtue |
| **Methodology** comparative case study using a physical model | Yes | Yes | Yes we iterative in process and minimize creating non-needed theories | Yes as the method assumes it can be repeated | N/A | N/A | N/A | N/A | N/A |
| **Research Design** data collection | Yes | Yes | Yes we are using a model and not real humans | Yes by repeatability | N/A | N/A | Yes trying to look at enough data to understand the relationships | N/A | N/A |
| **Research Design** data analysis | Yes | Yes | No may be over collecting the data needed for understanding | Yes | N/A | N/A | N/A | N/A | N/A |
| **Research Design** Data sampling considerations | Yes | No we are looking at what we can look at and maybe not at what we should be looking at | yes introducing no new considerations | For this research NO | Yes | N/A | The model can only give certain results and everyone can use the same model | N/A | N/A |

Continued

| | canons of science | | | | Ethics | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Determinism | Empiricism | Parsimony | Testability | Utilitarian | Rights | Fairness | Common good | Virtue |
| Findings | Yes | Yes the findings need to be a carefully examined | No the findings may not lead to a simple understanding | Yes, the model can be repeated | Yes the finding should provide a way to find balance between organizations and the search for more data | N/A | N/A | N/A | N/A |
| Limitations | Yes | NO only one model to look at | Yes, Limits are simple | N/A | N/A | N/A | **NO** All researchers don't have to use this model | N/A | N/A |
| Delimitations | Yes, assumes structure will provide order | only 2 (Nominal and Edge) structures are being looked at | No Proposed structure may be too complex | Yes other can derive a proposed structure from the available material | N/A | N/A | N/A | N/A | N/A |
| **Implications** theoretical | Yes uses a highly structure artificial environment | No does not look at the real world | NO | Yes allows new C2 theories to be tested | Yes | N/A | N/A | Yes there is common good when developing a new theory | N/A |

Continued

| | canons of science | | | | | Ethics | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Determinism | Empiricism | Parsimony | Testability | Utilitarian | Rights | Fairness | Common goou | Virtue |
| **Implications** methodological | NO | NO | No | Yes repeatability is provided | NO | Yes All Operational C2 researchers are provide a method to accomplish research that less costly and with less surity concerns that currently available | N/A | N/A | N/A |
| **Implications** practical | NO | New venue to observe Operational C2 | NO | Yes repeatable and could take the place of humans | N/A | N/A | N/A | Addative to the body of knowledge of C2 | N/A |
| Validity | Yes | Yes | No | No final validitation of C2 theories is war | N/A | N/A | NO | NO | NO |

Continued

| | canons of science | | | | Ethics | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Determinism | Empiricism | Parsimony | Testability | Utilitarian | Rights | Fairness | Common good | Virtue |
| Reliability | Yes ordered Universe | Yes | NO | Yes | N/A | N/A | NO | NO | NO |
| Future Research | Yes | Yes | Yes | Yes test other than in the crucible of war | Yes | Yes | Yes | Yes allow all understanding | Yes, Seek truth |

# APPENDIX B

**Dr. Richard E. Hayes**, founder and President of Evidence Based Research, Inc. (EBR), is trained as a political scientist, social psychologist, and a methodologist. He has a rich background in international relations, comparative politics, decision making under stress, economics, and defense analysis. He specializes in multidisciplinary analysis of intelligence and national security issues; the identification of opportunities to improve support to decision makers in the defense and intelligence communities; the design and development of systems to provide that support; and the criticism, test, and evaluation of systems and procedures that provide such support. His areas of expertise include: political instability and social violence; political and economic development; development and validation of indicator and forecasting systems; crisis management; political-military issues; research methods; simulation and modeling; test and evaluation; military command, control, communications, and intelligence (C3I); and decision aiding systems. He holds a Bachelor's degree from the Georgetown University School of Foreign Service and a Ph.D. from Indiana University.

## B.1 Notes from a Conversation with a Seminal C2 Author

On Day 2 of the CCRP 13$^{th}$ annual conference, I had an opportunity to have a long one-on-one conversation with Dr. Hayes. His words intrigued me: "The future of C2 is networking." Dr. Hayes expressed that C2 is never a goal in itself, but there are three components: enablers, process, and people. People that have a deep understanding of C2 see the human network as proactive followership: change the infrastructure and it changes the social network where edge-functions are critical. C2 will become more and more networked as the field becomes user quality controlled with less time dependence on a single user holding knowledge, as you have both symmetric and asymmetric communication accruing, and more and more open source specialties where knowledge is a shared common resource. Concepts like networked targeting will be the norm, because "small world" structures are easily accepted. Enablers like Wikis will enable small groups of trusted people to become corporative gatekeepers of knowledge. JEFX and the Air Force in general have not been the "poster child" for the C2 way ahead. C2 entropy in process is the adaption of people. What needs to be captured are the social networking functions. NATO has done some great work in the metrics' need for assessment. Efficiency and agility can still be dramatically improved within C2.

# APPENDIX C

Sense Making Agents

SenseMaking_Agent_1

<begin agent configuration parameters>

SenseMakingAgent_EBR.jar

com.ebrinc.elicit.agent.impl.SenseMakingAgent

readyIntervalDelay|Time interval to click Ready button|10000

screeningSelectedMessageDelay|Screening selected message (message processing) delay|1000

selectMessageFromQueueDelay|Select message from queue delay|1000

informationProcessingDelay|Information Processing delay|3000

pullBetweenSitesDelay|Pull between sites delay|1000

postBetweenSitesDelay|Post between sites delay|500

socialProcessingDelay|Social Processing delay|4000

sharingPostingMessageDelay|Sharing/Posting each Message delay|5000

awarenessProcessingDelay|Awareness Processing delay|3000

determiningKnowledgeNeedsDelay|Determining Knowledge Needs delay|3000

idAttemptDelay|ID Attempt delay|20000

webRequestDelay|Web Request (Pull)|9000

primary|Primary areas of interest. Possible values: who, what, where, when)|who,what,where,when

secondary|Secondary areas of interest. Possible values: who, what, where, when)|

isCompetitiveHoarder|IsCompetitiveHoarder|false isGuesser|IsGuesser|true

isFrequentGuesser|IsFrequentGuesser|true

idConfidencelevel|IdConfidencelevel|0.01

hasSeenEnoughToIdentify|HasSeenEnoughToIdentify|1

minSolutionAreas|The minimum number of ID tables with some data|1

partialIdentify|Identify if there are no some answers|true

timeBeforeFirstIdentify|Time before the agent does its first identify (in minutes)|1

shareBeforeProcessing|If true then share message before Processing|true

propensityToSeek|PropensityToSeek possible values (low, moderate, high, very high)|moderate

postedTypes|PostedTypes|who,what,where,when

sharedTypes|SharedTypes|who,what,where,when

postOutOfArea|PostOutOfArea|true

shareAccordingToSiteAccess|ShareAccordingto SiteAccess|true

shareRelevantAccordingToSiteAccess|ShareRelevantAccordingToSiteAccess|true

postToFactoidAreaSitesOnly|True if factoid must be posted only to the appropriate sites|false

minTimeBetweenPullsForPropensityToSeekLow|It is used to set minTimeBetweenPulls, if propensityToSeek is low. If the time since the last pull is not >= minTimeBetweenPulls, do not Pull (in milliseconds)|300000

minTimeBetweenPullsForPropensityToSeekModerate|It is used to set minTimeBetweenPulls, if propensityToSeek is moderate. If the time since the last pull is not >= minTimeBetweenPulls, do not Pull (in milliseconds)|180000 minTimeBetweenPullsForPropensityToSeekHigh|It is used to set minTimeBetweenPulls, if propensityToSeek is high. If the time since the last pull is not >= minTimeBetweenPulls, do not Pull (in milliseconds)|60000

minTimeBetweenPullsForPropensityToSeekVeryHigh|It is used to set minTimeBetweenPulls, if propensityToSeek is very high. If the time since the last pull is not >= minTimeBetweenPulls, do not Pull (in milliseconds)|60000

minTimeBetweenShares|If the time since the last Share is not >= minTimeBetweenShares, the agent should wait before it Shares (in milliseconds, -1 means ignoring this parameter)|-1

postFactor|PostFactor|1

pullFactor|PullFactor|1

shareWithFactor|ShareWithFactor|1

provideRelevance|Provide relevance for posted and shared messages|false

provideTrust|Provide trust for posted and shared messages|false

reciprocity|Reciprocity possible values (high, low, medium, na, none)|

trustInIndividuals|List of initial values of TrustInIndividual for players in agent's team. Possible values (high, medium, distrust, no opinion)|

trustInWebSites|List of initial values of Trust for web sites. Possible values (high, medium, distrust, no opinion)|

trustInSources|List of initial values of Trust for sorces. Possible values (high, medium, distrust, no opinion)|

messageQueueCapacity|Capacity of queue (-1 means unlimited)|-1 messageQueueTimeRemainInQueue|Time a factoid can remain in queue (-1 means unlimited)|-1

messageQueueNewerBeforeOlder|If true then newer messages are selected before older|false

futilityThreshold|Time working in an area during which no new messages in that area are processed before moving on to another area|-1

sharingModality||both

shareValueThreshold||none

shareTrustThreshold||none

shareSourceThreshold||dist

postBeforeProcessing||false

shareBeforePost||true

noSharingIfPosted||no

accessibleAgents||1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28

accessiblePostSites||sJFCwebsite1,sJFACCwebsite1,sCRCwebsite1,sWOCwebsite1,sASOCWebsite1,sCORPwebsite1,sSOCwebsite1,sFleetwebsite1,sTACCwebsite1,sC-CPwebsite1,sJFCwebsite2,sJFACCwebsite2,sCRCwebsite2,sWOCwebsite2,sASOCWebsite2,sCORPwebsite2,sSOCwebsite2,sFleetwebsite2,sTACCwebsite2,sC-CPwebsite2,sJFCwebsite3,sJFACCwebsite3,sCRCwebsite3,sWOCwebsite3,sASOCWebsite3,sCORPwebsite3,sSOCwebsite3,sFleetwebsite3,sTACCwebsite3,sC-CPwebsite3

accessiblePullSites||sJFCwebsite1,sJFACCwebsite1,sCRCwebsite1,sWOCwebsite1,sASOCWebsite1,sCORPwebsite1,sSOCwebsite1,sFleetwebsite1,sTACCwebsite1,sC-

CPwebsite1,sJFCwebsite2,sJFACCwebsite2,sCRCwebsite2,sWOCwebsite2,sASOCWeb
site2,sCORPwebsite2,sSOCwebsite2,sFleetwebsite2,sTACCwebsite2,sC-
CPwebsite2,sJFCwebsite3,sJFACCwebsite3,sCRCwebsite3,sWOCwebsite3,sASOCWeb
site3,sCORPwebsite3,sSOCwebsite3,sFleetwebsite3,sTACCwebsite3,sC-CPwebsite3

shareDistanceThreshold||1

inactivityPeriod||6000000

# VITA

## Marvin Leo "Lenard" Simpson, Jr.

Knowledge and experience span broad and diverse spectrum of operational and technical fields and complement extensive educational experience. Operational background includes air-to-air and air-to-ground fighter missions, including use of "special weapons," leading operational support teams, exercise planning, and 20+ years of MAJCOM staff experience in Command and Control (C2) informational systems. Lenard is recognized as an operational and technical Subject Matter Expert on Combined Air Operations Centers and operational air power. Accomplishes peer review for articles in national and international C2 journals. CAOC System Manager at Al Udeid Qatar (fourth Air Operations Center engaged in Combat operations). Familiar with most currently fielded C2 equipment and exercise-related modeling and simulation systems. Currently working for Northrop Grumman as a Senior Software Engineer support AOC WS 10.2 designing the Strategy Sub System and leading the System of Systems Architecture (SoSA) Operations team. Retired Air Force Field Grade Officer, served as Commander and Operations Officer for 8 years in Tactical Air Command (TAC), Pacific Air Forces (PACAF), and Air Mobility Command (AMC), experience in weapons operations/employment. Winner, Long Rifle III, combat proven ability, intercepted WARSAW Pact aircraft, and built and executed ATOs during actual military contingencies operations.

### EDUCATION

- MS/Administration, Central Michigan, Mount Pleasant Michigan, 1989
- BS/Mechanical Engineering Technology, Virginia Tech, Blacksburg Virginia, 1980

### PUBLISHED PAPERS

- Integration and Interoperability of Information Systems within the Coalition Aerospace Operations Center
- The Conceptual Requirements for an Operational Airpower Planning Tool
- A User's Epistle on Text Chat Tool, Acquisition, Governance of Collaboration
- Beyond Cybernetics (Risk Mitigation for a "Flat Earth" Information Milieu)
- Bettering National Response by Effectively Using the Combined Air Operations Center
- Using Response Surface Methodology as an Approach to Understand and Optimize Operational Air Power
- Extending ELICIT to Explore Command and Control in Operations Scenarios