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THESIS

**THE ABBOTT AND COSTELLO EFFECT:
WHO'S ON WHAT, AND WHAT'S WHERE WHEN?
A HUMAN-CENTERED METHOD TO INVESTIGATE
NETWORK CENTRIC WARFARE SYSTEMS**

by

Derek W. Read

September 2007

Thesis Advisor: Nita Lewis Miller
Second Reader: Lawrence G. Shattuck

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The thesis discusses the 'lessons learned' from this research effort and makes recommendations about future exercises and how to better populate the DMSC with data. Additional recommendations for changes to the processes and procedures for data collection are provided.

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THE ABBOTT AND COSTELLO EFFECT: WHO'S ON WHAT, AND WHAT'S WHERE WHEN? A HUMAN-CENTERED METHOD TO INVESTIGATE NETWORK CENTRIC WARFARE SYSTEMS

Derek W. Read
Captain, United States Air Force
B.S., Idaho State University, 1998

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September 2007

Author: Derek W. Read

Approved by: Nita Lewis Miller, Ph.D.
Thesis Advisor

Lawrence G. Shattuck, Ph.D.
Second Reader

James N. Eagle, Ph.D.
Chairman, Department of Operations Research

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TABLE OF CONTENTS

LIST OF FIGURES

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LIST OF TABLES

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Glossary of Acronyms

ATV	All Terrain Vehicle
AUV	Autonomous Underwater Vehicle
CDR	Commander
CDTEMS	Congressional funding from the Center for Defense Technology and Education for the Military Services
CIRPAS	Center for Interdisciplinary Remotely-Piloted Aircraft Studies
DMSC	Dynamic Model of Situated Cognition
DoD	Department of Defense
FINEX	Finish Exercise
GPS	Global Positioning System
GRADE	Geographical Recall and Analysis of Data in the Environment
HSI	Human Systems Integration
ID	Identify
IED	Improvised Explosive Device
ISR	Intelligence, Surveillance, and Reconnaissance
KM	Knowledge Management
MGRS	Military Grid Reference System
MIL-STD	Military Standard
MOUT	Military Operations on Urban Terrain
MS	Microsoft
NCO	Network Centric Operations
NCW	Network Centric Warfare

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I. INTRODUCTION

A. PREFACE

Accurate and timely information is critical to success in battle. Throughout history, commanders and foot soldiers have collected and transmitted battle information in various methods. These methods have included fire and smoke signals, homing pigeons, and runners. During WWII, new methods to exchange information included telephones, telegraph, and wireless radios. The twenty-first century has brought us fully into the digital age in which we transfer information to distributed locations over the globe by using wireless networks, the internet, and voice over IP (VOIP).

These technological advancements in communication cause a change in how warfare is conducted. Network centric warfare (NCW) systems are being rushed to the field offered as a solution for the ‘fog of war’ and as a way to reduce manpower costs. Many of the new technologies that enable NCW have given little consideration to the role of the human in the design or implementation of the system. There is an unstated and untested assumption that system performance is facilitated by the introduction of any new piece of equipment. This thesis will describe a method to test these assumptions by objectively assessing system performance using a process tracing approach. This proposed method will provide NCW system developers with the ability to collect objective data on the total system’s contribution to a shared understanding of the battlefield and provide decision makers with information on the limitations and capabilities of this technology.

This introductory chapter will first provide an overview of network centric warfare. Then a definition of Human System Integration (HSI) is provided to explain the process by which the individual domains of HSI are integrated in a human-centered design process. Lastly, three of the eight domains of HSI will be further defined within the context of NCW for the purpose of this thesis.

B. NETWORK CENTRIC WARFARE

Network centric warfare (NCW) is based on a concept of operations in which humans use technology to share information and the ability to rapidly utilize that information will result in increased military effectiveness. The goal of NCW is to increase combat power by utilizing all assets in the field and at home to electronically link decision-makers and shooters. With access to the same information at the same time, NCW theory suggests that this new technology will enable operators to achieve shared awareness resulting in increased speed of command, higher tempo of operations, greater lethality, increased survivability and better synchronization (Alberts & Garstka, & Stein, 1999; Alberts & Hayes, 2003; Cebrowski & Garstka, 1998).

The Department of Defense (DoD) is currently developing and fielding numerous versions of this networked technology, but the goals of NCW cannot be achieved with technology alone. NCW is an emerging theory of war and a new concept of operations, and it provides an opportunity to develop a human-centered system of systems. Network centric warfare requires a cultural change away from traditional hierarchical military relationships to include the new ability of networking over the Internet among large groups of people to accomplish a combat objective in real time. The technology itself will not be an optimal force multiplier unless humans are recognized as critical information nodes and sensors within the system.

In NCW the humans are vital to the system because they are required to define, forage and harvest the information needed to accomplish an objective. The goal then becomes developing a system that is both transparent and intuitive to the operator while providing critical information to decision makers in a timely manner. To this end, if a human-centered design is used in the development process, the cost for the entire life cycle of the NCW system may be reduced, allowing the overall system to operate more effectively.

C. HUMAN SYSTEMS INTEGRATION

Human Systems Integration (HSI) is a human-centered approach to the design, development, and acquisition of systems from cradle to grave. A fundamental premise of HSI is that any new materiel solution must consider the humans involved in the system. The acquisition process should include human considerations early in the design, thereby enhancing human-system performance. Implementing HSI early in the acquisition process can result in a reduction of total lifecycle costs, and better overall system performance.

To achieve a human-centered design, HSI professionals provide a comprehensive management and technical strategy for human systems integration. This HSI plan is a DoD requirement as stated in the 5000.2 series instruction document (USD/AT&L, 2002). While there is considerable debate about the number and names of the HSI domains, the Naval Postgraduate School, which offers the only graduate degree in HSI, uses eight domains in its definition of HSI. These eight domains are: Human Factors Engineering, Manpower, Personnel, Training, Human Survivability, Health Hazards, System Safety, and Habitability. Following is a description of each of these eight HSI domains.

1. Training

The instruction, education, and training required to provide personnel with the knowledge, skills and abilities needed to operate and maintain systems (NPS, 2006). For example, on-the-job training is an organization's attempt to assist task specific learning through instruction, observation, or practice that reflects the demands of a job.

2. Personnel

The knowledge, skills, abilities, aptitudes, and experience required for the human component of the system to enable the system to achieve full capability (NPS, 2006). Personnel selection is based upon the tasks that are to be performed to complete a job. For example, operators, maintainers, and support personnel would have different KSAs and experience.

3. Human Factors Engineering

A design and development process that focuses on the interaction between human beings and the tools, equipment, machines and systems they employ to achieve system effectiveness and safety (NPS, 2006). There are two objectives within a human-centered design: consider ergonomic design (the hardware) and create an intuitive and transparent system (software) for the operator.

4. Manpower

The total demand, expressed by the number of individuals, required to fill jobs, slots, or billets for a system with consideration for total life cycle requirements to include the big areas of both operational and support (NPS, 2006). For example, manpower would represent the number of bodies required to supervise, train, maintain and operate an aircraft, but does not represent KSAs required for each billet.

5. System Safety

System safety is the application of engineering, management, and HSI principles, as well as human factors design criteria, and techniques to achieve acceptable levels of risk hazard for mission requirements and system capability (NPS, 2006). For example, a weapon system is designed to reduce the chance of death or injury to operators within the constraints of operational effectiveness, cost, schedule, and performance throughout all phases of the system life cycle.

6. Human Survivability

Human survivability is the ability of a system and its personnel to avoid or withstand hostile environments without jeopardizing mission accomplishment (NPS, 2006). For example, in the case of a tank, it is the ability of the crew and the overall system to continue to function during and after a disturbance from something as simple as a rollover due to terrain or as complex as withstanding a direct hit from an armor piercing round.

7. Health Hazards

Health hazards are anything that can have a harmful effect on health either during the system's production, operation, or maintenance to include decreased worker performance and significant long-term health risks (NPS, 2006). For example, health hazard specialists may be concerned with the toxicity/lethality of jet fuel and the personal protection equipment (PPE) required for personnel to work in and repair aircraft fuel cells.

8. Habitability

Habitability is concerned with the qualities of the physical living environment and support services within a system which lead to mission effectiveness (NPS, 2006). Using a space station as an example, it is important that the crew resting quarters are away from heat and noise (physical stressors), the work area has adequate space to prevent overcrowding (psychological stressors), and that there are adequate facilities for food preparation, bathing and waste removal. These accommodations will contribute greatly to the performance of the crew and the total system.

D. THE RELATIONSHIP BETWEEN NCW AND HSI

This thesis uses a human-centered approach that encompasses the following three domains of HSI: training, personnel, and human factors engineering. These three domains will now be defined within the context of NCW.

1. Training

NCW systems require a transition from legacy systems and concepts of operations to information age weapons, equipment, and technology (Money, 2001). This transition also requires new concepts of operations that facilitate new strategies and tactics by providing training for decentralized rapid operations for use in asymmetrical warfare. NCW systems require that operators receive training in both computer/digital skills and in communication and coordination within horizontal and vertical networks.

2. Personnel

To reduce training time and cost for NCW systems, it is imperative to select and place the correct personnel in the right jobs (Money, 2001). For the NCW system to perform optimally, personnel will need to have information technology skills, an aptitude for multitasking, and experience in a position that requires the individual to fulfill many roles and duties simultaneously.

3. Human Factors Engineering

NCW systems need to have a human-centered design to maximize their potential (Money, 2001). For example, designing computer displays that support situational awareness and control of real-time and dynamic processes for NCW means more than just presenting the data in a form that supports the workflow of the operator. To enable effective understanding of the battlespace, it is necessary to portray the information in a manner that supports the cognitive capability and goals of the operator. HFE is critical in all cases where the operator is performing at the extremes of his or her performance envelopes.

II. LITERATURE REVIEW

This chapter reviews literature from the fields of network centric warfare (NCW), team performance, development of virtual teams, and situated cognition.

A. NETWORK CENTRIC WARFARE

The current direction of the DoD has shifted from platform-centric warfare to NCW or network centric operations (NCO) (Cebrowski & Garstka, 1998). The potential of information age warfare was first recognized in the 1983 invasion of Grenada, reinforced in the 1990 Persian Gulf War, and widely accepted in the 2003 invasion of Iraq and the war on terror in Afghanistan (Wilson, 2004). Networked information technologies supplied the forces with unprecedented battlefield advantages during these wars. These information technologies are capable of providing leadership with real-time awareness of current theaters. Reportedly, operators in the field who use NCW systems are also experiencing increased situational awareness on the battlefield (Garstka, 2003; Blash, 2003). The current Department of Defense trend is to reshape the US military as a network centric force that will be able to leverage information to increase speed and combat effectiveness.

NCW combines various types of information technologies to produce information superiority that is reputed to increase combat power through self-synchronization and other network centric operations (Alberts, 1999; Alberts & Garstka, 2001; Wilson 2004). A robust, secure and broadband network plays a crucial role in future warfare in which the network will connect all types of sensors in the air, on land, and under the sea. Ideally, the network will assist with logistics to ensure the timely supply of troops and help synchronize conventional, electronic, and information attacks.

B. TEAM PERFORMANCE

Outcomes in time–critical, high-risk situations are often dependent on crisis action teams or “tiger teams” in which expertise, information, and tasks are distributed across highly trained and specialized individuals. The effectiveness of these teams requires rapid, complex, coordinated behavior, resulting in integrated team performance. The high degree of interdependence that is inherent in such teams makes the performance requirements of individual members particularly demanding (Kozlowski, Gully, McHugh, Salas, Cannon-Bowers, 1996a). Previous research indicates that the contribution of team members is not simply an additive function of each individual. Rather, the patterns of communication, information flow, and responses which indicate a shared mental model of team members enables the team to respond to externally driven and constantly changing task demands (Thordsen & Klein, 1989; Fleishman & Zaccaro, 1992; Weick & Roberts, 1993). To achieve high team effectiveness, it is believed that teamwork-building or enabling skills may be needed to facilitate a congruent and synchronous mental model of action for team members (Kleinman & Serfaty, 1989).

Thus far, research in the field of team performance has led to an increasing focus on work teams within organizations and on how best to build teamwork skills that are the foundation of team effectiveness (Kozlowski, Gully, McHugh, Salas, Cannon-Bowers, 1996b). The literature suggests that any team, including a command and control team, requires a certain amount of time to become effective. However, the opportunity to spend time together as a team is not always available. This can be seen in real world emergencies where effective ad-hoc teams come together in a short period of time. For example, teams formed quickly for Hurricane Katrina emergency care. And in NCW a team may be formed at any time from members distributed around the globe (Kayes, 2003).

In the scientific literature, teams are distinguished from other collectives by the characteristic of shared interdependent work (Thordsen & Klein, 1989; Salas, Dickinson, Converse, & Tannenbaum, 1992). In comparison, terms “group” or “work group” include work collectives who see themselves and are seen by others as social entities with common goals but with looser task connections (Thordsen & Klein, 1989).

Several theories describe the stages teams pass through as they evolve (Bennis & Nanus, 1985; Bennis & Shepard, 1956; Bion, 1961; Schultz, 1958; Tuckman, 1965; Tuckman & Jenson, 1977). These models provide a description of developmental stages of teams and suggest that team development is a process that occurs over time. The models further indicate that much of the time required to develop the team is spent on social rules and norms that reduce interpersonal conflict while increasing the productivity of the team. For example, Tuckman's (1965) model consists of the following four stages: forming, storming, norming, and performing. Although this model is a stage model, it does not imply a progressive directionality to a team's ability to pass through the stages. In other words, a team can revisit any of the stages, for example, going from forming to storming and then back to forming again. These, stage models suggest a time-consuming process to develop an effective team. Although the issues mentioned are one aspect of team development, the models are not able to explain rapid ad-hoc team formation during time-critical events such as military operations.

C. VIRTUAL TEAMS

Understanding team performance becomes even more important for NCW because technological advances, globalization, organizations, and global militaries are moving toward utilizing more network structures and team-based functions (Lipnack & Stamps, 1997). The term ‘‘virtual team’’ is becoming more prevalent as teams move from being primarily ‘‘co-located,’’ where team members are in one physical location, to ‘‘virtual,’’ where team members may be located anywhere on the globe, separated by space and time.

For definition purposes, virtual teams will be considered groups of individuals who interact through various communication technologies to accomplish common goals. Virtual learning teams are being used in education and corporate training programs in an attempt to enhance collaboration and cooperative learning experiences. Even though various studies of groups using computer-mediated communication have contributed to an increased understanding of both face-to-face and virtual teams, the results are inconclusive (McGrath & Hollingshead, 1994). Most studies comparing face-to-face groups and groups using communication technology suggest that face-to-face teams are more effective. McGrath and Hollingshead (1994) examined fifty studies on computer-assisted group performance and found that computer-mediated groups tend to have fewer interactions and less information exchange among members than face-to-face groups. Virtual team members can exchange verbal information as efficiently as a face-to-face team, but they lack the ability to convey non-verbal cues as easily as individuals that are co-located. This lack of non-verbal communication can contribute to increased misunderstanding among members (Warkentin, Sayeed, & Hightower, 1997). Research also indicates that face-to-face teams have better internal leadership and coordination than virtual teams (Burke & Chidambaram,1994; Eveland & Bikon, 1989).

Theoretical development and empirical research are needed to better understand and respond to the challenges that virtual teams face (Furst, Blackburn, & Rosen, 1999). Although there have been several related studies in this area, few research efforts have focused on rapid–forming, ad-hoc successful teams. In the case of real world examples, which are often investigated after the fact, these temporary, newly-formed team members have a limited history of working together and have few prospects of working together in the future. Therefore, the question exists: how is it that they succeed?

D. DISTRIBUTED SOCIAL NETWORKS

Many organizations are similar to networked communities in that they have multiple sets of work team members (including multiple supervisors), geographically seperated relationships, and teams of co-workers shifting by the day and week as employees get involved in multiple projects. The situation is different from that dealt with by traditional organizational theory, which defines organizations as densely knit workgroups neatly structured in bureaucratic, hierarchical organizational trees (Wellman, 1997). How do people work together in large, sprawling, networked organizations where they are members of multiple, transitory, physically dispersed teams simultaneously? In particular, how do people in such organizations obtain knowledge from others when they do not know whom to ask?

These questions are of immediate practical importance for NCW. The key to making NCW effective is not only in connecting geographically dispersed forces, retrieving information from sensors, human intelligent agents and other information sources, but also analyzing different information, generating useful knowledge and then distributing it to the right person at the right time in the right format. This enormous task explains why computer-supported solutions are being developed to work through trusted interpersonal relationships to identify, locate, and receive information within and between communities and organizations (Wellman, 1997). It is not surprising that research in knowledge management (KM) has been driven by computer scientists and communication scientists interested in building tools for harvesting knowledge and then managing the growing database. The critical issue of tracking who knows what information at any given time is a more complex task in networked organizations (Cross & Borgatti, 2000). Traditionally in an office setting, an individual will first examine documentation or other help sources from their desks before wandering out into a hallway in search of friendly colleagues. The problem becomes acute, however, in distributed communities (Ackerman & McDonald, 1996).

E. SITUATIONAL AWARENESS

Situational awareness (SA) is a concept that grew from lessons learned in the battlefield. SA has been defined as “adaptive, externally directed consciousness” (Dzierzanowski, 1999). The United States Army has defined it as the ability to maintain a constant, clear mental picture of the tactical situation (Dzierzanowski,1999). This mental picture includes an understanding of the terrain and the relationship between friendly and enemy forces (Dzierzanowski,1999).

SA as defined by Endsley as: "…the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1995; Wickens et al., 2001).

The definition by Endsley, as applied to an object in the environment tries to answer these questions: *what* is it, *what* is it doing, *why* is it doing it, and *what* will it do next. However, this definition misses an important element of SA which is the context within one's own situation and not just an awareness of external objects. SA should also include an acknowledgement of one's own psychological state (Omedei, Wearing, McLennan & Hansen, 2001). Not all objects in the environment need to be monitored all the time. At any given time some elements will be less important than others, but Endlsey suggests that some level of awareness is required of each element, to monitor changes in levels of importance (Endsley, 1993).

Another view of SA is that it is a detailed appreciation of what is happening now and what is likely to happen in the immediate future. This statement can be compared with commander's intent which focuses on the overall end state to be eventually achieved from an understood start state.

According to Endsley, an operators' SA exists in one of the following three levels of complexity (1995, 2001):

Level 1 consists of perception of elements in the environment.

Level 2 involves comprehension of the current situation.

Level 3 incorporates the prediction of the future actions of data elements.

Considerable effort has been invested in devising methods of quantifying SA, measuring SA and training to improve the ability to acquire SA (Gawron, 2000; Nofi, 2000; Endsley, 2001; Endsley & Robertson, 2000). Methods of measuring SA range from the highly intrusive to the deliberately unobtrusive. In the former, the activity is suddenly stopped and the immediate SA of participants is captured in some way usually a series of questions to be answered for later comparisons with ground truth at that time. One issue with this method is that it interrupts the activity, possibly degrading the level of immersion the participant has in the exercise/experiment. Unobtrusive measures typically require participants to self rate their SA retrospectively. This post hoc reporting procedure relies on participants' memories of events that may have occurred much earlier in time. SA at any point in time is unlikely to be fixed in long term memory because SA is a process that ebbs and flows with ground truth. A retrospective query to asses SA may provide an average SA score over the entire scenario or a specific score for a single point in time.

F. SITUATED COGNITION

NCW theory makes a fundamental assumption that improved information infrastructures will facilitate military decision-making and, therefore, military effectiveness. Previous work linking NCW applications to military effectiveness efforts have had difficulties in modeling the decision-making aspects of the process (Hazen et al., 2003). Advocates of NCW suggest the prime advantage of NCW systems is in the generation, communication, and mining of operational information.

To test these premises, it is necessary to empirically assess the contribution of any new technology and other contributions to the NCW system such as training and personnel selection. Therefore, a model which assesses the effectiveness of an NCW system must include a decision-making model. Models of information throughput and human decision-making should inform decision makers of the capability of weapon systems. These models should not assume that all information is accurate, understandable, timely, cognitively matched, and fully used by the decision-maker. In fact, previous research indicates that it is not the quantity or quality of the data but rather the contextual nature of the information that is important in determining value to a decision-maker (Fewell & Hazen, 2004).

The Dynamic Model of Situated Cognition (DMSC) provides a conceptual model that is useful for modeling military decision making (Miller & Shattuck, 2004; Miller & Shattuck, 2005b). The schema used for classifying decisions is based on Naturalistic Decision Making (NDM) theory (Klein, 1997; Shattuck & Miller, 2005). In this approach, process tracing provides a robust understanding of contributions of both the operators and the system to a decision-maker's actions (Miller & Shattuck, 2004; Miller & Shattuck, 2005a; Shattuck & Miller, 2004). The DMSC is composed of 6 ovals and three lenses (see Figure 1).

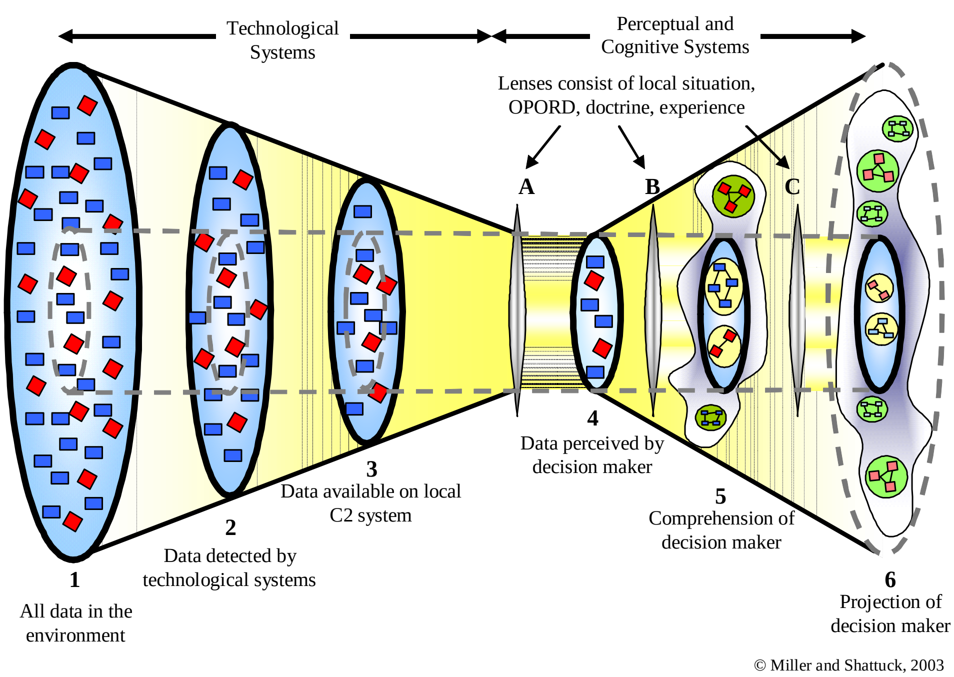


Figure 1. Dynamic Model of Situated Cognition (From: Miller & Shattuck, 2004).

Oval 1 consists of all data in the battle space to include blue and red forces, non-combatants, terrain features, weather, and sensor location. Oval 2 represents the data collected by the sensors. Oval 2 is smaller than Oval 1 due to the fact that no sensor array will detect everything in the environment. Oval 3 represents data displayed on operator screens. Oval 4 is the operator's perception of the data. Oval 5 represents the comprehension while Oval 6 is a projection of current data.

The model also has 3 lenses (labeled A, B, C in Figure 1) which mediates how information is processed by the decision maker. According to the model, the lenses direct the attention of the decision maker toward certain data, and in some cases, skew what information is perceived (See Figure 2). Thus, as lenses change shape, attention will shift; decisions may be influenced by the change in these lenses (Miller & Shattuck, 2006).

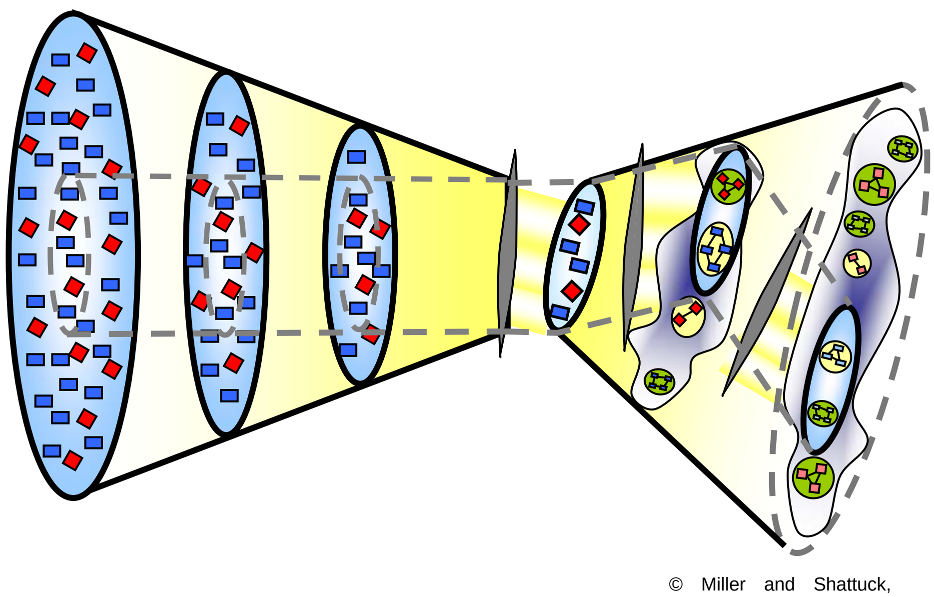


Figure 2. Distortions in the lenses lead to inaccurate perceptions, comprehensions, and projections (From: Miller & Shattuck, 2006).

Miller and Shattuck suggest that each lens has a purpose which is listed in Table 1 and that there are currently 6 classes of information within the lenses as can be seen in Table 2 (Miller & Shattuck, 2005).

Table 1. Purpose of Each Lens.

Lens	Proposed Purpose
Lens A	Directs attention
Lens B	Mediates information organization
Lens C	Course of action

Table 2. Classes of Information Embedded in Each Lens.

• Individual states and traits • Social factors • Local context • Plan • Guidelines • Experience

Enhancements to the original model include the addition of quantifying accuracy and certainty, feedback loops (see Figure 3) that represent the iterative nature of decision-making, and to teams (see Figure 4) (Miller & Shattuck, 2006).

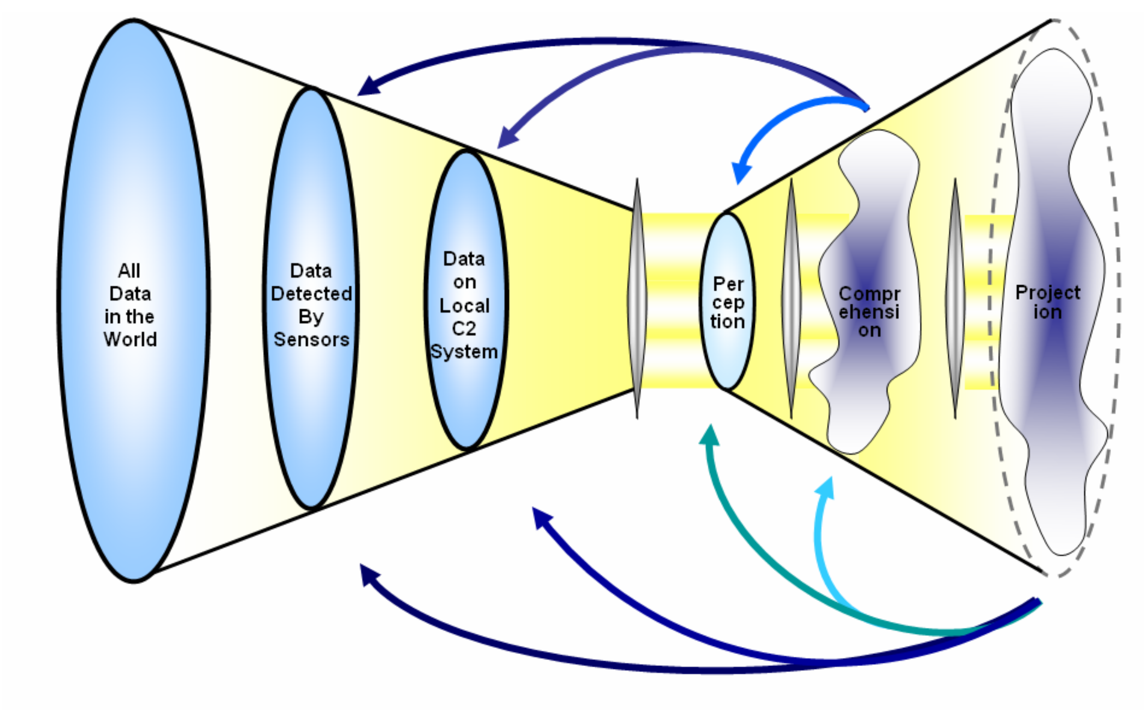


Figure 3. Feedback Loops in the DMSC (From: Miller & Shattuck, 2005).

In the case of NCW it is important to have a model that incorporates not only each technological system input, but also the various inputs from each human node in the system. NCW, by its very nature, is considered to be a collaborative effort and as can be seen in Figure 4, the DMSC is capable of representing these team interactions.

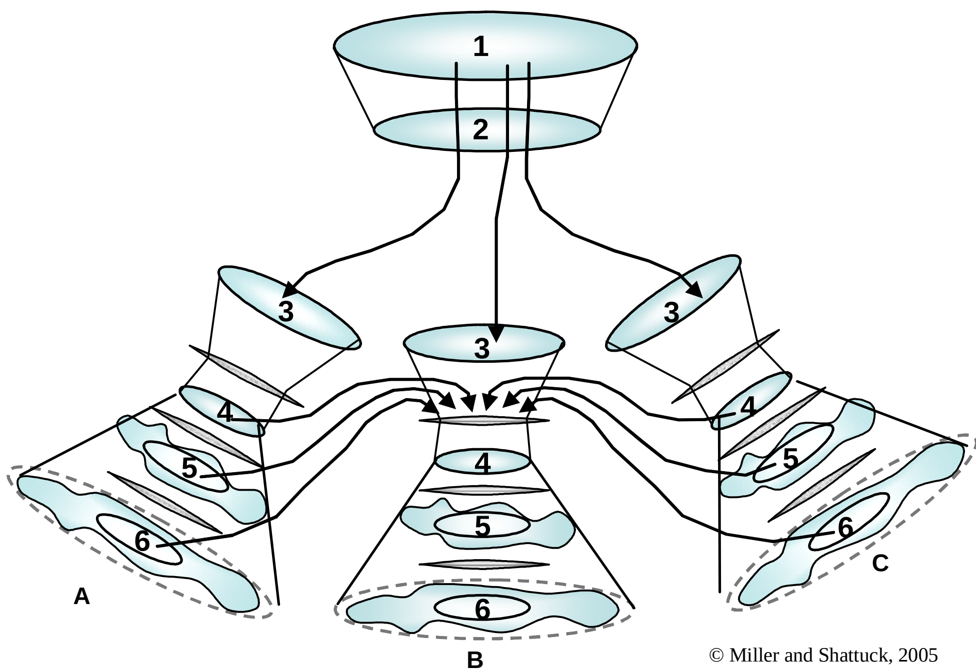


Figure 4. DMSC Applied to Teams (From: Miller & Shattuck, 2005).

The merit of the DMSC model has been recognized by multiple organizations. However, to fully test the model and explore its use as a method to evaluate complex systems, there needs to be a reliable and accurate method for determining the contents of each of the six Ovals of the DMSC. One candidate tool for accomplishing this is a situated cognition measurement tool called the Geographical Recall and Analysis of Data in the Environment (GRADE). GRADE was conceived as a measure to illuminate what participants' were attending to during a Future Combat Systems experiment (Miller &

Shattuck, 2006). Currently GRADE provides only qualitative data to the researcher, but that data provides situated cognition over time of what each participant knew of the battlespace and when they knew it. GRADE has continued to demonstrate efficacy in populating Oval 4 in multiple field studies (Miller & Shattuck, 2003; Miller & Shattuck, 2005; Miller & Shattuck 2006).

This thesis describes using GRADE as method and process by which the DMSC model can be validated and applied in the field setting for NCW research.

III. METHODS

A. OVERVIEW

As previously stated, there is not a well-defined methodology for evaluating the human and technological components of a network system. This shortcoming in NCW makes it difficult to determine whether hardware, software, or changes to organizational structures or procedures really improve warfighting capabilities. This thesis uses the DMSC as the theoretical framework for NCW and, in addition, proposes GRADE an evaluation strategy that is based on that model. GRADE examines the contents of each of the six ovals in the model to determine who knew what and when they knew it. This methodology also nominates appropriate metrics and discusses techniques for analyzing data in both laboratory and field settings.

While GRADE has been used in several laboratory and field experiments to assess command and control activities (Miller & Shattuck, 2007), the tool itself has not been assessed to determine its efficacy in such data collection venues. GRADE provides a method to collect a participant's situated cognition and then use that data to populate Ovals 4 and 5 of the DMSC. With Ovals one through five populated it is then possible to trace how data and information propagate through the NCW system over time.

B. VENUE

The Naval Postgraduate School conducts field exercises quarterly in the Tactical Network Topology (TNT) program. This series of exercises provides an opportunity to collect NCW data in a field environment. Since the program is receptive to input from investigators in the design and development of scenarios, it is possible to influence data collection activities. The Naval Postgraduate School (NPS) TNT Program began approximately four years ago with the purpose of providing the opportunity for students and faculty to evaluate some of the latest technologies in an operational environment and, when appropriate, to rapidly transition these technologies to the warfighter. The program relies heavily on the operational knowledge of the NPS faculty and student body as well as a very close working relationship with United States Special Operations Command (USSOCOM). Congressional funding from the Center for Defense Technology and Education for the Military Services (CDTEMS) together with funding from USSOCOM and the Office of Force Transformation (OFT) has permitted one to two week long quarterly field exercises to be conducted, using laboratories on the NPS campus, the NPS Beach Laboratory and the Center for Interdisciplinary Remotely-Piloted Aircraft Studies (CIRPAS) (Marina Airport), Monterey Bay, the Military Operations on Urban Terrain (MOUT) facility at Fort Ord, U.S. Coast Guard (Oakland) facilities, and an NPS CIRPAS UAV test facility at the California Army National Guard, Camp Roberts, CA.

The field exercises began with a series of Surveillance and Target Acquisition Network (STAN) exercises which have transitioned to the Tactical Network Topology (TNT) Program which focuses on providing the soldier on the ground the ability to push or pull video, data, text messages, and use voice over IP (VOIP) to communicate with other soldiers and with other ISR assets in both rural and urban environments. In addition the network provides screens that display 'situational awareness' and blue force tracking. It utilizes air and ground based wireless networks, satellites, unmanned vehicles (UAVs, UGVs, AUVs, airships, tethered balloons), unattended ground sensors, handheld PDAs, and laptops to enhance situational awareness and to enhance our ability to find, fix, and identify enemy personnel and equipment.

TNT 07-03 was conducted 11 through 18 May 2007 at Camp Roberts, California. This field exercise consisted of the following scenario activities: Perimeter Security, Border Surveillance, Area Search, and Identify/Monitor Area/Activity. The data for this research effort were collected on the morning of 17 May 2007 during a baseline scenario.

The assigned mission for the five members of the Blue Forces was to monitor the borders for trespassers. In the event a trespasser was spotted, they were to conduct surveillance and monitor their activity.

The assigned mission for the three members of the Red Force was to cross the borders at different locations. Red 1 was to drop off the material for an IED at a certain location. Later Red 2 would stop by the predetermined location and assemble the IED. The last part of the mission was to have Red 3 set up the IED at that location for use and simulate detonating the device.

1. Participants

Data were collected on participants in the following positions during the 17 May 2007 morning scenario. Participants in the following positions completed the GRADE measures and wore digital audio recorders.

- Tactical Operations Center (TOC) Commander
- Air Boss
- Raven 3 (UAV)
- Buster (UAV)
- SORSE (five individuals)
- Red force commander
- Red vehicle 1
- Red vehicle 2
- Red vehicle 3

Although Raven 3 participated in the exercise, the GPS location data on this UAV were never captured due to technical difficulties with Cursor on Target software making it impossible to establish ground truth for this vehicle. The Raven 3 GRADE data were compared to the other GRADE data to determine if participants correctly populated the measures.

Special Operations Research, development, test & evaluation Support Element (SORSE) is the Blue force ground troops and was composed of five individuals. Three of them rode on ATVs while the other two drove in SUV's. Red1, Red2, and Red3 comprised the red force ground troops. All three drove their own civilian vehicles.

2. Apparatus and Instrumentation

As discussed previously the DMSC is composed of 6 ovals. The first three ovals are comprised of the technological system's contribution and the last three ovals are the human contribution to the total system. It follows that measurements should follow this division. Table 3 indicates the measures that could be used to populate these ovals. In the case of the current research project, data were captured primarily for Ovals 1, 2, 3, 4 and 5 of the DMSC for the TNT 07-03 field experiments.

Table 3. Measures used for populating DMSC.

Oval	TNT Field Experiment
1	GPS network Network data storage
2	Sensor network Network data storage Sensor capabilities
3	Screen captures for individual players
4, 5, 6	GRADE Digital voice recorders Acetate overlays (Oval 6)

To maintain a consistent temporal reference, both the GRADE measures and digital voice recorders were synchronized to the GPS network time. To capture data for Oval 1, ground truth data were collected from each vehicle's GPS tracking system and stored by the TNT network. Commercial GPS units were used by the ground forces; UAV position was captured by software broadcast of GPS position. In the case of the ground troops, the GPS units were linked with laptop computers that had wireless connectivity with the TNT network. GPS data were sampled at a rate of once per second for the duration of the scenario. Figures 5 and 6 provide examples of GPS data collection and storage.

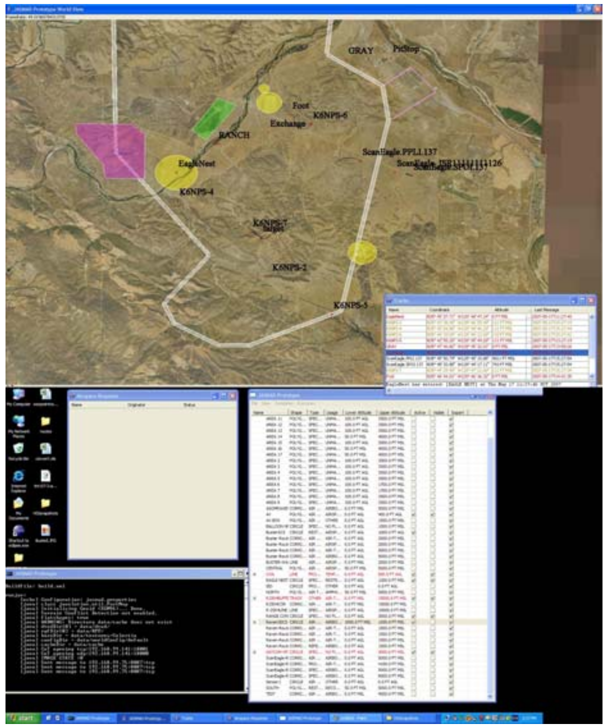


Figure 5. Tech Data.

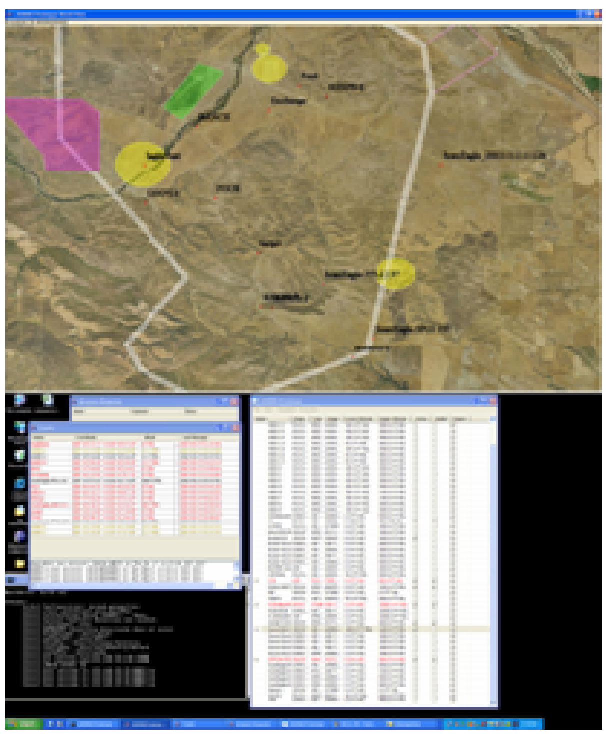


Figure 6. Tech Data + time.

Oval 2 data were captured first by understanding a sensors' capability and secondly by providing data on where the sensor was looking. In the case of the former, a full understanding of what a sensor could see or hear is taken into consideration for correctly identifying hits and misses of participants. For example, an audio sensor is not going to provide a picture enabling participants to visually ID a vehicle; similarly, a small UAV flying at 10,000 feet is not going to have the resolution required to allow identification of moving ground targets. In the latter case, it is not enough to know where a sensor is, but it is also essential to know where it is looking. The Scan Eagle UAV was capable of providing this capability by providing its own location and the location where the camera was looking. This was achieved by software that could calculate the location the camera was looking by calculating camera position versus UAV location. With a field of view calculation researchers could theoretically determine the exact area viewed by the sensor throughout an exercise. Unfortunately, the Scan Eagle UAV did not participate in the 17 May AM scenario.

Oval 3 was populated by collecting screen captures of what was on participants' displays at fifteen minute intervals (see Figures 5 and 6).

Oval 4 and 5 data was captured by a combination of both the situated cognition measure GRADE and digital voice recorders. GRADE was collected in this case using a map of the area of operation for the TNT 07-03 experiments (see Figure 7). Multiple blank GRADEs, a clipboard, and a blue and red Sharpie fine point permanent marker were provided to each participant.

Figure 7. GRADE example.

Nine Olympus WS-300M digital voice recorders were used to collect audio data from the participants. To ensure the maximum understanding of voice data, omnidirectional microphones were used in conjunction with the digital voice recorders.

3. Procedure

The procedure section is organized to indicate how data was collected for each Oval of the DMSC during the TNT 07-03 field experiment. This section will start with Oval one and conclude with Oval five.

a. Oval 1

Careful advance collaboration with TNT exercise planners enabled an understanding of what sources of data were available to be collected and then used to populate the first three Ovals. For Oval 1 all UAVs and ground vehicles were equipped with GPS units that were able to broadcast to the TNT network. Location data was sampled and saved once per second.

b. Oval 2

For Oval 2 all data provided by technological sensors were time stamped as the information was passed into the TNT network.

c. Oval 3

For Oval 3 a screen capture of what was presented on the displays was captured every 15 minutes. In addition, in the Tactical Operations Center a time-stamped digital log was kept of what UAV video feed observers noted. Finally, the TOC CDM and Air Boss wore digital voice recorders providing further information on what information was available on the displays.

d. Oval 4 and 5

The decision makers listed in the Participants section (above) were trained in the GRADE protocol. The GRADE was administered every twenty minutes during the exercise. The Air Boss would announce over the radio network time to complete a GRADE to the Blue forces while Red Commander would make the same announcement to Red forces. Participants were instructed to provide their understanding of the battle space on the GRADE maps (see appendix A). The GRADE instructions were as follows:

Please complete the GRADE every 20 minutes after STARTEX until FINEX according to the following instructions.

1. Turn away from your information display, monitor etc.
2. Record your duty positions (e.g., Air Boss, Red1, etc.) and the current time in the upper left portion of the map.
3. Use the ***blue marker to identify*** where you believe the blue forces are located. Draw a circle around each blue entity to indicated your confidence/certainty. ***A small circle indicated high confidence/certainty. A large circle indicates low confidence/certainty.***
4. Use the ***red marker to identify*** where you believe the ***red forces*** are located. Draw a circle around each red entity to indicate your confidence/certainty. ***A small circle indicates high confidence/certainty. A large circle indicates low confidence/certainty.***

The top left corner of the GRADE map indicated the TNT experiment and date of data collection. Blanks were provided for participant position information and time the GRADE was conducted.

4. Data Analysis Plan

Prior to collecting the data at Camp Roberts, a plan for analyzing the GRADES was developed. The plan included converting latitude/longitude data provided by GPS devices to military grid coordinates. Then, a master location spreadsheet would be created that listed the military grid coordinates for all relevant entities in the battlespace for each time the GRADE was administered.

SORSE

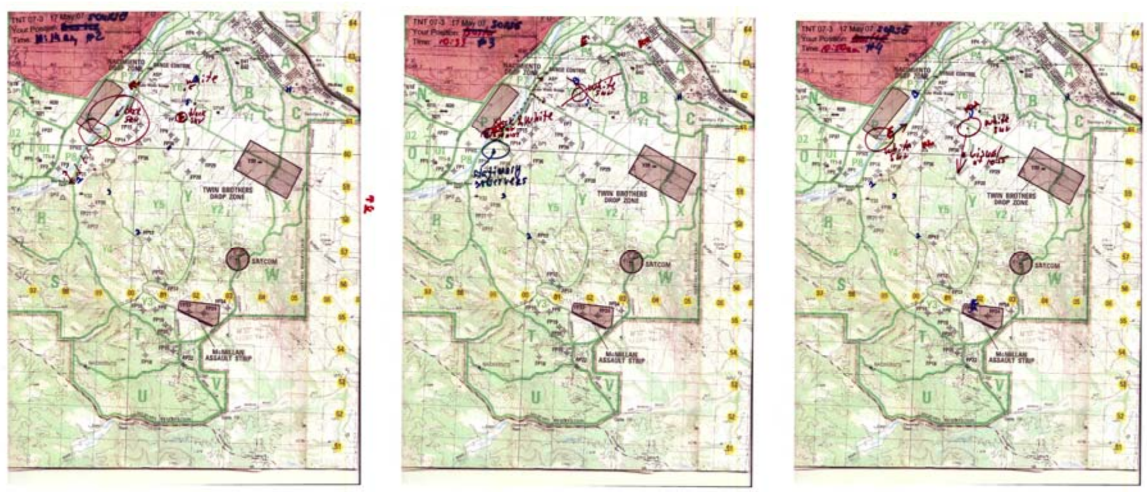
Time	Easting	Military Grid	Northing	Military Grid	ID	Notes	Ground Truth East	Ground Truth North	Vehical	Key
9:50		100		6000	B	B	98345	58897	ATV1	1
9:50							10	5740	ATV2	2
9:50							9920	5860	ATV3	3
9:50							450	6190	Hyundai	H
9:50							150	6140	Jeep	J
9:50									Scan UAV	SU
9:50		280		6130		B			Scan Cam	SC
9:50		140		6080		Buster	190	6110	Buster	B
9:50		120		6110		White SUV	9790	5920	Kurt	Ku
9:50							130	6090	Klop	Kl
9:50							140	6120	Erik	E
10:14		100		6000		B	9830	5890	ATV1	1
10:14							10	5740	ATV2	2
10:14							9920	5860	ATV3	3
10:14							450	6190	Hyundai	H
10:14							150	6140	Jeep	J
10:14									Scan UAV	SU
10:14									Scan Cam	SC
10:14							170	6210	Buster	B
10:14		9950		6080		Black SUV	810	5840	Kurt	Ku
10:14		130		6090		Black SUV	9990	6190	Klop	Kl
10:14		140		6180		White	130	6080	Erik	E
10:33		9880		5990		stationary reserves	9830	5890	ATV1	1
10:33							0	5740	ATV2	2
10:33							9920	5860	ATV3	3
10:33							450	6190	Hyundai	H
10:33							160	6140	Jeep	J
10:33									Scan UAV	SU
10:33									Scan Cam	SC
10:33							120	6240	Buster	B
10:33		9860		6040		Black SUV	310	6350	Kurt	Ku
10:33		9860		6040		White SUV	9890	6060	Klop	Kl
10:30							130	6190	Erik	E
10:50							9840	5890	ATV1	1
10:50							0	5740	ATV2	2
10:50							9920	5860	ATV3	3
10:50							450	6190	Hyundai	H
10:50							150	6140	Jeep	J
10:50							180	5510	Scan UAV	SU
10:50							190	5520	Scan Cam	SC

Figure 8. Location data spreadsheet.

Military grid coordinates for each participant's entries on the GRADE sheets would also be determined. The participants' marks for each entity would be compared with the actual (ground truth) location and the distance between the actual (ground truth) and the recorded (actual) would be calculated (see Figure 8 for an example).

With the DMSC populated with data it is now possible to use the GRADE data (Ovals 4 and 5) to look back through Ovals 1, 2, and 3 to determine the errors, if there were any, in a participants' perceived ground truth of the battlespace. For example, a researcher may notice a point where a participant incorrectly identified a vehicle. The data trace would possibly provide this information: a Red force unit crosses a border (Oval 1), but is not yet detected. A UAV (sensor) flies by the enemy capturing an image (Oval 2). The video feed flows through the network and is displayed on an observers screen (Oval 3). The participant notices the vehicle (Oval 4) and then incorrectly labels it a Blue force vehicle (Oval 5). Now the researcher can try to determine where the error was introduced. Was it because the display did not provide enough resolution (Oval 3) or due to the lens between Ovals 4 and 5 indicating to the participant only Blue forces are in that area.

Figure 9 illustrates the GRADE measures ability to capture a participant's situated cognition (Ovals 4 and 5) over time. These figures include the ground truth overlays.



SORSE GRADE 3 SORSE GRADE 4+20 SORSE GRADE 5+20

Figure 9. GRADE data and ground truth from SORSE at approximate 20 minute intervals.

IV. RESULTS

Due to the high rate of missing data, quantitative statistical analysis could not be completed for this thesis. Instead, a descriptive analysis of Participants' performance on GRADE, ground truth vs. perceived truth, and a qualitative analysis of the digital voice recordings is provided.

A. GRADE DATA

The data collected from GRADE immediately indicated to the researchers that there are issues in how the participants populated the GRADE over the course of the scenario. As table XX indicates, nine participants completed 57 GRADE measures over the course of the two hour experiment. Out of the 57 GRADEs generated, not a single GRADE was completed correctly indicating that participants did not follow instructions. To salvage the data collection, it was determined that if at least one Red or Blue force was clearly labeled, that GRADE would be considered usable. With this new criterion, 21 GRADE measures provided useful data indicating a 37% ratio for completed GRADEs (see Table 4).

Table 4. Total GRADEs vs usable GRADEs.

Position	GRADEs Completed	Usable GRADEs
Air Boss	7	0
Buster (UAV)	7	2
Raven (UAV)	6	0
Red Queen	6	0
Red 1	6	5
Red 2	6	6
Red 3	6	4
SORSE	6	4
TOC CC	7	0
TOTAL	**57**	**21**

Further analysis of the 21 usable GRADEs indicates only 44 usable data points out of a possible 282 data points resulting in 16% usable data for this research effort. This result is artificially low due to the assumption that participants would know where all players were at all times. A more accurate measure of GRADE performance is achieved by contrasting the 44 usable data points against the 131 actual data points found on the GRADE maps. In this case the GRADE measure provided 34% usable data return.

As Table 5 indicates, there were a possible 513 total detections during the course of this scenario. Participants only indicated 262 actual detections yielding a 51% success rate of detecting either red or blue forces. Both Blue (105) and Red (50) forces did better at detecting themselves than at detecting the opposing force.

Blue force had a total of 167 detections indicated on the GRADE measures. 62 of those detections were of Red forces while the remaining 105 were of friendlies indicating a 37% rate of detecting enemy forces. Red force had fewer players in the scenario, so it is not surprising that their total detection of 95 is lower than the Blue force. Red force had 45 Blue force detections indicating a 47% rate of enemy force detections.

Table 5. Detections.

Detections	**Blue**	**Red**	**Total**
Possible	342	171	513
Actual	150	112	262
By Blue	105	**62**	167
By Red	**45**	50	95

Table 6 indicates a different result for the TOC Commander who has the potential capability of having positions for all 6 Blue force assets and 3 Red force assets. The same measurements already described were used to populate this table.

Table 6. Qualitative examination of TOC CDR GRADE data.

Ground force	**Know Self/friendly**	**Enemy**
TOCC CC (Blue)	6	3

At first glance the table would lead one to believe that the TOC Commander had an accurate representation of the battle space. This is an artifact due to averaging the Blue and Red force marks. The raw data indicate a different story (see Table 7). In fact, there were GRADEs that indicated up to 8 Blue force locations (there were only 6 Blue force entities) and up to 4 Red force locations (there were only 3 Red force players).

Table 7. TOC Commander Raw Data.

Blue	Red	Total
8	0	8
5	3	8
6	2	8
6	2	8
5	4	9
5	4	9
5	3	8

B. GROUND TRUTH VS. PERCEIVED TRUTH

Due to the numerous incorrectly completed GRADEs and the different times GRADE measures were completed, it was impossible to create a common picture of the battlespace at any point in time. The next best solution was to determine if there were participants who identified each other at close temporal points. This criterion change yielded three participants who had completed GRADES within seven minutes of each other (see Table 8). This data indicates that within a seven minute period, the Blue force knew the exact location of Red 2 and Red 3. This battlespace knowledge was better than Red 1 (Red 2 error = 100m; Red 3 error = 200m) or Red 2 (Red 2 error = 200m; Red 3 error = 200m) knowledge of the battlespace.

Table 8. Raw data near temporal point one.

Participant	Time	GRADE #	Vehicle	Error in meters
SORSE	9:50	1	R2	0
	9:50	1	R3	0
Red1	9:44	2	R2	100
	9:44	2	R3	200
Red2	9:43	2	R2	200
	9:43	2	R3	200

One hour later as seen in table 9, the same three participants completed GRADEs at nearly the same time. This data set spans a six minute period in which the Blue force lost Red 2, detected Red 1 (Red 1 error = 700m) and had more error in Red 3; Red 3 error = 300m). Both Red 1 (Red 2 error = 500m; Red 3 error = 1300m) and Red 2 (Red 2 error = 300m; Red 3 error = 800m) knew of their locations.

Table 9. Raw data near temporal point two.

Participant	Time	GRADE #	Vehicle	Error in meters
SORSE	10:50	4	R1	700
	10:50	4	R3	300
Red 1	10:44	5	R2	500
	10:44	5	R3	1300
Red 2	10:50	5	R2	300
	10:50	5	R3	800

C. AUDIO DATA

The audio recordings from the following four participants were transcribed: TOC Commander, SORSE, Red 1, and Red 2.

An overall analysis of the data from Blue forces indicates that Blue participants primarily reported on the detections and locations of Red forces and Red activities. There were four instances of military grid coordinates on Red forces being passed over the Blue radio network and many referrals to land marks near the Red forces (e.g., under tree or near ranch house). One interesting question from the Buster UAV ground control unit to SORSE ground forces was, “Have you reported any of these things yet? I’ve just been sending them [pictures].”

TOC Commander audio logs indicated that he provided very little input to SORSE. In fact there is only one instance in the two hour scenario that he provides information to SORSE about a vehicle coming down a road.

SORSE audio logs indicated some confusion coming from the Buster ground control unit about what pictures to take. There is one instance at 10:10 am of Blue 3 passing an incorrect report on a Red vehicle location and its activities.

An overall analysis of the Red forces voice recordings indicates that Red forces primarily reported on their own locations and activities. Red 1 audio logs indicated that he could hear the Blue forces radio net. In fact, when Blue forces would report detecting a Red player, Red 1 would report in to Red commander that Blue forces were correct. Red 1 had the least amount of data out of these four analyses.

Red 2 audio logs indicated occasional UAV sightings, but mainly consist of comments on Red force locations and activities. Red 2 was very concerned with STARTEX and FINEX times for the scenario.

V. DISCUSSION

Some members of the Department of Defense believe the NCW assertion that technology will provide a multiplicative effect to US military forces resulting in improved capability and mission effectiveness. However, to date there are no empirical findings that support or refute the claims put forth by the architects of NCW.

This thesis proposed an objective method to evaluate NCW system assumptions by objectively assessing system performance using a process tracing approach. Data collection occurred on 17 May 2007 in the field at Camp Roberts, California during TNT 07-03 field experiment. Due to a high data loss, statistical analysis for supportable conclusions could not be drawn from the GRADE measure. Thus the DMSC could not be validated by this thesis in a field setting.

Following is an analysis of what went well and what went awry with the overall GRADE administration including instructions for GRADE, adequacy of training for participants filling out GRADE, quality control issues for the GRADE, and finally, a discussion on the scope of the experimental data collected.

A. GRADE DATA

Many factors contributed to the inability of the GRADE measure to provide usable data. An after action review of the researchers' processes and procedures to populate the DMSC and evaluate the GRADE measure provided the following items as factors that hampered the data collection effort.

Oval 1 – Ground Truth was collected by having all vehicles equipped with GPS that broadcasted their locations to the TNT network. After an initial review of the GPS data it was noted that there were some issues with this technological solution establishing ground truth. Multiple vehicles had time periods for which no GPS data were recorded; the Raven UAV yielded no usable data. Access to GPS data for a fast moving vehicle (e.g., a UAV or automobile) is critical to accurately place it in the battlespace over the course of a scenario. The need for frequently updated GPS location data for vehicles that are moving slowly or standing still is less critical.

If the DMSC is to be a viable approach to the assessment of NCW it is important to consider the issues and challenges associated with establishing ground truth. GPS systems were the technological method chosen to record the participants' locations at the TNT event. Although GPS systems are fairly accurate, the data they yield still has some degree of error. There is a possibility of an error of up to 100 meters from the physical GPS location due to a variety of factors (e.g. atmospheric conditions, ephemeris error, clock drift, measurement noise, selective availability, multipath, dilution of precision, obstruction).

Oval 2 – Sensor Data were collected by determining the platform's capability and then by collecting data on where the sensor was actually pointed. At the TNT event, researchers had a full understanding of the platform's capability prior to the scenario. In the later case, there are two particular sensor issues that need to be resolved.. The first concerns UAVs and the second the human participants.

For this TNT, there were GPS locations for the Buster UAV; however, the GPS locations were not available for what the camera saw. This problem contributed to errors in scoring the data for detections. For example, it is possible the ground truth data will indicate Buster flew over Red1 which may be could potentially be a hit. However, further analysis may indicate that Buster was actually banking hard to the right when it passed over Red1, putting the camera's focus away from the target. In terms of the DMSC model, ground truth or data populating Oval 1 never made it to Oval 2 due to the sensors inability to detect Red1. This missing data will propagate through the model presenting a false representation of the battlespace for Oval 3 which results in the participants' inability to perceive this data for Oval 4 and comprehend it in Oval 5..

Another problem occurred when trying to capture where the human sensors (i.e., the exercise participants) were actually looking. Currently, there is not a process in place to collect these data during TNT experiments. This inability to capture the actual information perceived by the participants leads to scoring errors when trying to determine hits, misses, or other categories. As discussed in Chapter III, it is not enough to know where a sensor platform is located, it is also essential to know where it is looking in order to populate Oval 2. This applies to both human and technological sensors.

Oval 3 –Oval 3 was populated by capturing screen shots of the Air Boss's monitor in the TOC at 15 minute intervals. Fifteen minute data sample intervals do not provide enough fidelity to populate Oval 3. Only five of six screen captures were potentially useful, and of those, only two aligned temporally with two different participants' GRADE measure completion times. One of the main reasons screen captures were not usable was because they did not have time stamps on them, making them difficult to integrate them into the other data.

Oval 4 & 5 – Oval 4 (Perception) and Oval 5 (Comprehension) data were collected using the GRADE and digital voice recorders. In the case of the former, all participants made errors in indicating their understanding of the battlespace on the GRADE maps. On a few GRADEs, only one color marker (blue or red) was used to identify both Red and Blue forces. Often there were blue or red marks but no identification with which to compare that mark to ground truth. In other instances, unique identifiers were used but the researchers could not determine what they represented.

There is not a consistent temporal referent across data samples since participants did not complete the GRADE at the precise time they were instructed. The morning scenario on 17 May 07 had an official start time of 09:04 with an expected first GRADE of 09:24. Actual initial GRADE start times ranged from 09:20 through 09:40. Within a participants GRADE measures there was variability such that the GRADEs were not always taken at twenty minute intervals. In fact, there was enough temporal discrepancy that three participants completed one additional GRADE.

The digital voice recorder data were not without error either. Some of the voice recordings were lost when some participants accidentally turned off the digital voice recorders or when participants placed the recorder down and walked away, forgetting that they were supposed to keep it on their bodies. Another issue with digital voice recorder data is the lack of speech intelligibility due to background noise or wind blowing over the microphone.

B. GRADE INSTRUCTIONS

The inconsistencies in how each participant filled out their GRADE measures indicated that the instructions were not clear. One apparent issue with the GRADE instructions is that it was not clearly stated that when marking the location of Blue or Red forces, the participant must identify the blue or red mark. For example, if the participant knew that the Honda SUV belonged to Red 1 they should have placed a red dot on the map and annotated near it, "Red 1."

Participants also did not follow the first instruction which stated that participants needed to look away from their displays while completing the GRADE. Two participants' GRADEs closely mirrored ground truth, indicating they were using the GRADE to represent what was on their displays (Oval 3 data) rather than where they were focusing.

C. GRADE TRAINING

Due to inconsistencies in how participants filled out their GRADEs, there appears to be a lack of understanding by the participants of what is required to complete the forms. These inconsistencies clearly indicate inadequacy in training. This should not be surprising since there were no formal processes or procedures for the training of participants in how to complete a GRADE. This inadequacy was due to time limitations of participants and the lack of personnel available to conduct the training. Again, this is not surprising since participants in the TNT experiments do not have much extra time. Typically, participants are so heavily task loaded to execute the scenarios they do not have time for a formal class before or between scenarios to receive training.

The second reason is the lack of personnel available to participate in data collection. Generally one or two researchers try to spend a few minutes with each participant to offer 'just in time training' before a TNT scenario began. For the scenario this thesis investigated, there was only one researcher available to collect data from nine participants, most of whom were not collocated with the researcher.

D. QUALITY CONTROL FOR GRADE

There were no formal processes or procedures for quality control checks of the GRADEs completed by the participants. This is primarily due to the assumptions that participants would receive training in how to complete the GRADE and that the GRADE was not difficult to complete. As already mentioned, it was impossible for a single researcher to check on the nine participants' GRADE measures each time they were completed.

E. RESEARCH EFFORT SIZE

The inadequacy of the GRADE data collection resulted from researchers trying to capture too much data in the hope of being able to reconstruct ground truth for the entire two hour scenario. This goal overstretched the limited resources and personnel available for these data collection efforts. All the issues discussed up to this point can be traced back to the problems that arose when trying to collect too much data with too few assets.

In the event that this research effort had collected all the data initially planned, the total amount of data would have been enormous and would have taken several months to process for analysis. For example, processing the data for Ovals 4 and 5 on the TOC CDR, SORSE, Red1 and Red2 required approximately 40 hours of effort from four full-time research assistants.

Completing this analysis of what went well and what went awry with the processes and procedures of administering the GRADE measure provided researchers with a framework in which recommendations could be generated and a future course of action could be planned for the next data collection opportunity.

VI. CONCLUSION

A. CONCLUSION

Network Centric Warfare systems need to be empirically tested in order to validate developers' claims of enhanced capability and mission effectiveness. The Dynamic Model of Situated Cognition was selected as a way to model and test NCW systems due to its proven merit and recognition by many organizations as a way to model human system performance. The goal of this research project was to determine if the GRADE could be used as a data collection strategy and process by which the DMSC model could be validated in a field setting for NCW research. Unfortunately, that goal was not fully realized with the TNT 07-3 data collection effort. However, it was not the DMSC model or the GRADE that contributed to the poor data collection results, but rather inadequacies in the process and procedures employed to populate the DMSC and GRADE. The results of this research effort in no way refute the efficacy of the GRADE or the DMSC to model NCW in the field. These results have brought to light procedural errors in the methods used on GRADE administration.

Following are recommendations that will optimize GRADE data collection in future TNT experiment opportunities. Then, the next section describes the need for an automated or digital GRADE, which is then followed by a section describing a different strategy to analyze certain events of interest.

B. RECOMMENDATIONS

GRADE instructions. Since the TNT exercise occurs every quarter or so, participants have had experience in completing GRADEs in past TNT experiments. Participant errors indicate the instructions have some ambiguity and allow for interpretation of intent. Following are suggested instructions to improve the quality of GRADEs.

1. Grade Instructions for All Participants

Please complete the GRADE every 20 minutes after STARTEX until FINEX according to the following instructions.

1. **Do not look at any display while completing GRADE.**
2. Record your **duty position** (e.g., Air Boss, Red1, etc.) and the **current local time (using GPS or cell phone)** in the upper left portion of the map.
3. Use the **blue marker** to indicate **where** you believe the Blue forces are located;
4. Use the **blue marker** to identify **who** you think it is. If you are unsure of which Blue force it is, put a **question mark** next to the location mark.
5. **Draw a circle** around each Blue entity to **indicate your confidence/certainty** that they are located where you indicated. A small circle indicates high confidence/certainty. A large circle indicates low confidence/certainty.
6. Follow the same procedure for Red Forces with your red marker.
7. Use the **red marker** to indicate where you believe the Red forces are located and then use the **red marker** to identify **who** you think it is. If you are unsure of which red force it is then use a question mark to identify the location mark. Draw a circle around each red entity to indicate your confidence/certainty that they are located where you indicated. A small circle indicates high confidence/ certainty. A large circle indicates low confidence/certainty.

GRADE training. Training will reduce inconsistencies in how participants complete GRADEs. Creating a training folder is a solution that should facilitate training in as short a time as possible. The training folder could consist of:

1. A three ring binder.
2. Accurate geo-referenced maps of the area of operations.
3. Opposite the GRADE map should be a page with instructions indicating what needs to be done to complete each practice GRADE (GRADEs should be completed until there are no errors).
4. A blue and a red permanent marker should be provided.

The instructions for participants to follow to complete the practice GRADE could include the following:

1. Your position is Red1.
2. The time is 09:20.
3. Indicate the placement of Blue2 anywhere on the map and indicate that you are highly confident in that location.
4. Indicate the placement of Red3 anywhere on the map and indicate you have low confidence in that location.
5. Indicate the placement of a Blue force on the map that you cannot specifically identify and indicate you are highly confident of its location.

Researchers should generate several versions of the practice instructions varying time and Blue/Red force identity.

Recommended procedures to follow for training are as follows:

1. Have the participant read the GRADE instructions. Answer any questions the participant may have.
2. Flip to the first GRADE practice problem and have the participant read the instructions and then complete the practice GRADE.
3. Review the Practice GRADE for errors and have the participant complete another practice GRADE. Repeat until the participant has completed three in a row correctly.

Using this method to complete GRADE training should ensure correctly completed measures and usable GRADE data returns.

Quality control checks for GRADE. Quality control checks should occur immediately after each practice GRADE and after the first actual GRADE is completed. If the suggested instructions and training are used, quality control checks may need to be conducted when the participants turn in their completed GRADES.

C. FUTURE FOR GRADE

One possible solution to reduce data collection error is to create a digital or automated GRADE. This will reduce the overhead of supplies needed to complete the GRADE. A digital GRADE could also provide the capability of forced choice responses thus removing a major contributor to the error in the data collected for TNT 07-03. Furthermore, a digital GRADE will ensure standardization in how participants complete the GRADE and will provide a consistent temporal referent. The proposed computerized GRADE should have the following capabilities:

1. File Manipulation Capabilities

- Import geographic maps with specific UTM, Lat/Long or MGRS ranges.
- Save and load the currently annotated geographic map.
- Export user annotations and the result of disparity analysis to a commercially available spreadsheet software (e.g., MS Excel) for tabulation and statistical analysis.
- Import user defined symbols to complement MIL-STD 2525B symbols (i.e., common warfighting symbology) and provide them in the annotation tool bar.

2. Annotation Capabilities

- Capability to indicate position and strength of friendly, enemy and other individual and unit icons on the map.

- Software library of icons (including MIL-STD 2525B) and the capability to create and add new icons.
- ‘Click and drag-able’ capability for icons.
- Ability to place confidence or certainty circles around icons.
- Ability for user voice-over narration while drawing.
- Ability to draw battlefield graphics (e.g., avenues of approach and axis of advance).
- Ability to collect and distinguish “ground truth” from perceived or predicted truth.

3. Analysis Capabilities

- Real time analysis of current data.
- Compute disparity between ground truth and reported conditions.

D. FUTURE STRATEGIES FOR POPULATING DMSC

Researchers need to reevaluate the current Ground Truth data collection strategy. Researchers are using a process tracing method to examine the effects of task, environmental, and individual difference factors over the course of a two hour scenario to make inferences about decision strategies and the situated cognition that may have contributed to choosing a course of action. To accomplish this goal, researchers try to collect as much data as possible to build an accurate representation of what occurred during a two hour scenario. This large amount of data must be collected from multiple sources and time stamped. It is critical to have a single temporal referent when combining multiple data sources to achieve an accurate representation of what occurred, more over with out a single temporal referent it may become impossible to combine multiple data sources.

One data source that needs to be changed is the current method used to populate Oval 3. With the benefit of hindsight, it is apparent that more frequent screen captures would have been better than once every fifteen minutes. A better method to collect data for Oval 3 would be to video tape the display of interest and store this video recording on a hard drive. Storing the footage on a hard drive would remove the step of converting video tape storage to hard drive storage for later analysis.

Rather than trying to reconstruct an entire two hour scenario, it may be better to identify key events of interest and then perform process traces on these events. Smaller vignettes require less data to populate the DMSC and are easier to analyze. Then, over time as data collection processes and procedures are refined, researchers can attempt to capture entire scenarios. Researchers should collaborate with TNT planners to include smaller or more focused vignettes for data collection opportunities. These vignettes would maximize researchers' efforts to collect data and ensure that the right data are collected to allow a process trace of events of interest through the DMSC. The vignette data collection efforts would be a useful step to demonstrate the efficacy of GRADE as a method and process by which the DMSC model can be validated and applied for field research of NCW systems.

The GRADE continues to demonstrate potential to capture situated cognition not only in laboratory settings, but also in field settings. Following the recommendations in this thesis it will be possible to capture Ovals 4 and 5 in future research. This provides the ability to populate all the Ovals of the DMSC model. The DMSC then could be used to empirically test different NCW systems, thus providing decision-makers a more thorough understanding of the capabilities of each NCW systems.

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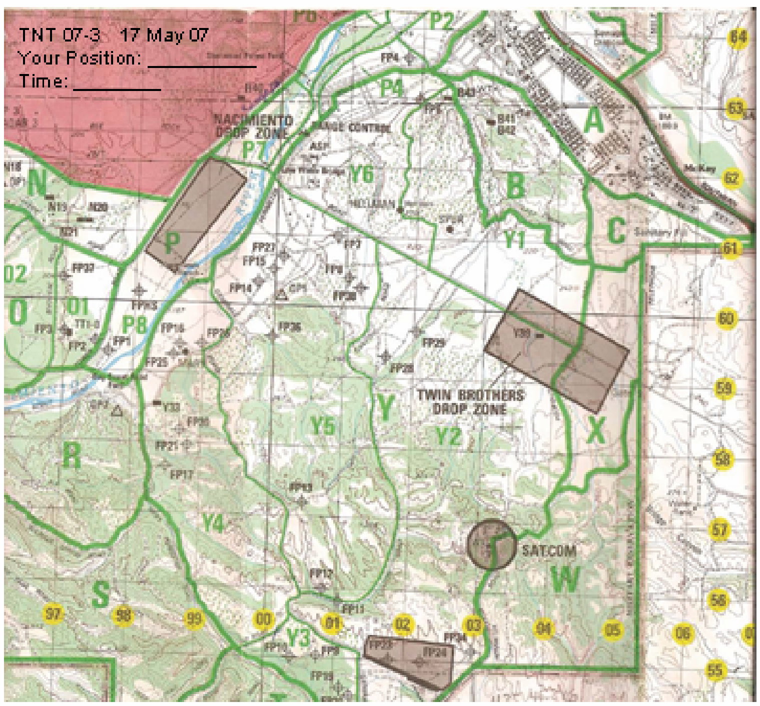
APPENDIX. GRADE

Instructions for GRADE

(Geographical Recall and Analysis of Data in the Environment)

Please complete the GRADE every 20 minutes after STARTEX until FINEX according to the following instructions.

1. Turn away from your information display, monitor, etc.
2. Record your duty position (e.g., Air Boss, Red 1, etc.) and the current time in the upper left portion of the map.
3. Use the *blue marker to identify* where you believe the *blue forces* are located. Draw a circle around each blue entity to indicate your confidence/certainty. *A small circle indicates high confidence/certainty. A large circle indicates low confidence/certainty.*
4. Use the *red marker to identify* where you believe the *red forces* are located. Draw a circle around each red entity to indicate your confidence/certainty. *A small circle indicates high confidence/certainty. A large circle indicates low confidence/certainty.*



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