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Assessing the Operational Impact of Network Centric Technology, Collaborative User Defined Operational Picture: A Controlled Experiment with Warfighters* (Final Draft Paper I-095, Rev 6/12/06)

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Abstract

In a controlled Human-In- The- Loop (HITL) experiment new Network Centric Warfare (NCW) technology was introduced to a dozen experienced warfighters in the form of a collaborative User Defined Operational Picture (UDOP) enabled by a wide area network as a possible improvement over their use of current baseline technology in the form of the Common Operational Picture (COP) with CHAT capability. The results showed significant improvements on the NCW performance metrics of Situational Awareness, Shared Situational Awareness and bottom-line Combat Effectiveness, across several phases of the Operation Storm Petrel scenario played out by the joint warfighting teams due to use of the collaborative UDOP in the experiment trials. The important role of enhanced planning quality, enabled by the collaborative UDOP, suggests it as a NCW metric that warrants more scrutiny by the research community. The majority of the participating warfighters were positive in their key assessments of the collaborative UDOP.

Introduction

During the past decade the doctrine of Net Centric Warfare (NCW) has emerged and grown. NCW has been 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 degree of self - synchronization. (Alberts, Garstka, and Stein (2000)) Situational Awareness (SA), as well as its sharing by linked warfighters (SSA), is thus deemed to be a major causative factor in increasing combat power. Besides the higher connectivity created through the construction of broader band networks, the major information technologies that are indispensable for enabling NCW for a warfighting team are the Common Operational Picture (COP) coupled with a shared whiteboard for collaboration over the map of the battlespace. DISA's most advanced versions of these technologies are the **User Defined Operational Picture (UDOP),** as instantiated by NECC C2 Common Services with the **Lightweight Collaborative Whiteboard (LCW).**

***Acknowledgments.** We wish to thank the DISA Net Enabled Command Capability (NECC) program that sponsored this experiment, and DISA's Joint Interoperability Test Command that provided knowledgeable and professional observers throughout its execution. DISA's Net Centric Enterprise Services provided the C2 Common Services of security, messaging, content discovery, and the Defense Online Portal. The JFCOM J9 Joint Systems Integration Center provided us a welcoming

Does greater Situational Awareness and its sharing by a distributed warfighting team enabled by a network in fact cause improved combat effectiveness? What are some of the causal mechanisms involved? The **purpose** of the experiment described here is to demonstrate and to analyze the differences in operational effectiveness between current warfare practices and NCW practices using the combined technologies of the UDOP and collaboration technology, while capturing quantitative measures of NCW parameters under controlled conditions. Here collaboration technology is instantiated through the LCW shared map planning capability with audio.

Approach

In the approach adopted here, variable Situational Awareness was experimentally created in a team context via the UDOP/CollabTech prototype in a **controlled Human-In-The-Loop (HITL) experiment** and related to combat outcome. (See TTCP GUIDEx, 2006) In the experiment each of four warfighting teams, each composed of an Air Force officer and a pair of Naval Tactical Action Officers (TAO), play out four battles, composed of modified versions of a Persian Gulf air/sea counter-terrorist combat scenario, termed Operation Storm Petrel, crossed with three versions of information technology, the prototyped UDOP/Collab Tech, the baseline COP/CHAT ensemble, and the combination of the two technologies. The baseline technology is that currently in use by most of our forces for scenarios similar to ours.

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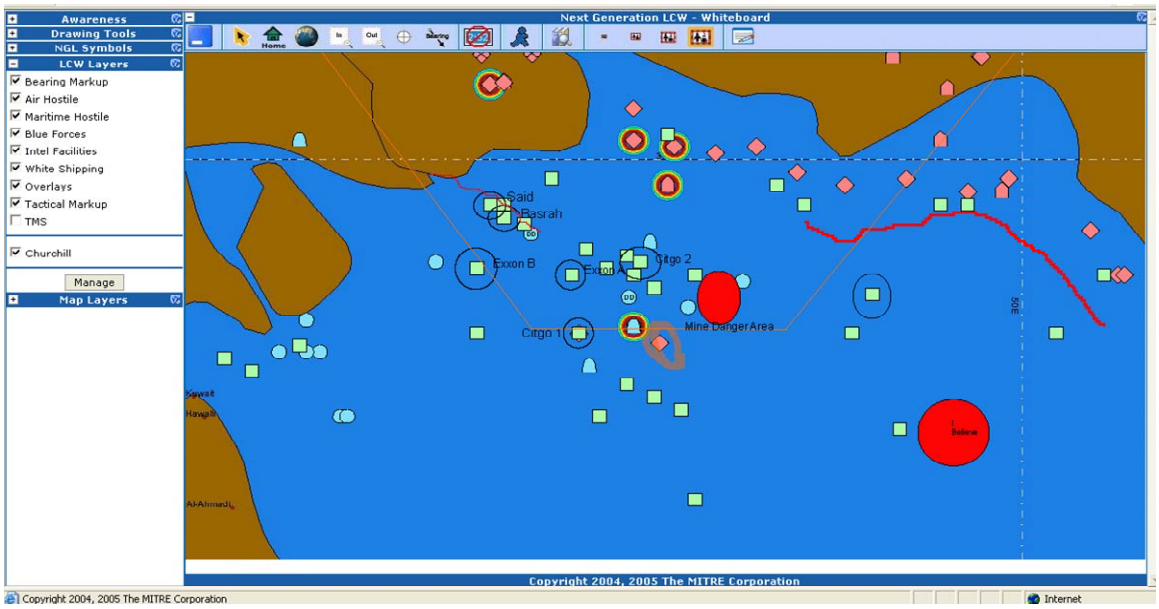
home lab environment and smoothly operating baseline technology; J7 provided us JTLS simulation support. Commander, Fleet Forces Command provided eight Navy players; HQ USAF and Langley helped provide four Air Force players. We wish to give special thanks to these warfighers for giving us of their valuable time and expertise to permit such an experiment. Finally, we wish to thank SPAWAR Human Systems Integration Center for valuable advice and support throughout the development of this experiment.

The mission of the blue teams, including the two ship captains protecting two major and six minor oil platforms off Basrah in the Persian Gulf, was to identify and to prosecute advancing terrorist fast attack craft and pirated aircraft. In each scenario run, one of the Naval officers played the role of captain/TAO of the guided missile destroyer USS Winston S. Churchill with all its resources (e.g. guns, missiles, helicopter), the other Naval officer played the role of captain/TAO of the guided missile destroyer USS Mason with all its resources and the Air Force officer played the role of Air Operations Coordinator (AOC) – controlling all fixed wing blue aircraft in the simulation. Opposing these blue force were a dozen terrorist fast attack craft, Boghammers, and two pirated Cessnas or two stolen MIG 29s . There were also two other blue ships, USS Arctic and USS Ardent, and dozens of neutral ships and commercial aircraft in the area. Each of the four slightly modified scenarios was divided into three time phases: TP1 consisting of Stage Setting and initial combat operations; TP2 consisting of Replanning triggered by a surprising new terrorist assault against oil platforms or US Naval ships, involving red fast attack craft or pirated aircraft; and TP3 consisting of the End Game of the combat operation. The basic scenario is analogous to the Basrah terrorist incident of Spring 2004 as well as to Operation Praying Mantis of 1986.

UDOP Screenshot of Scenario



NCW Metrics. For all four newly created three-man teams and for each time phase of all four trials, **Situational Awareness (SA)** is defined as the proportion of the crisis relevant, or mission critical, set of warfighting platforms, red, blue or neutral, correctly identified as important by the commander. (Hiniker & Entin, 1990; Hiniker, 2002; Perry et.al, 2004; Hiniker, 2005) During the simulated combat operation, using the JTLS wargame simulator, the commander's realization of the situation, his Situational Awareness, was obtained by his drawing on a map the platforms he deemed important at that time, i.e. by his personal Cognitive Operational Graphic (COG). The commander's proportion correct was then obtained by comparison with the platforms on the simulator's Ground Truth map at the same time. Greater overlap between the commander's COG and Ground Truth is indicative of greater Situational Awareness by the commander at the time. Greater overlap between the COGs of the team of three commanders is indicative of greater **Shared Situational Awareness (SSA**). (Hiniker, 2001; Hiniker, 2002; Perry et al, 2004) Thus these SA metrics take account of the fit for each mission relevant weapons platform between its psychological world cognition, its information world record and its

physical world existence. Such COG measures, together with a set of additional measures including current Plan quality and teamwork were obtained by trained observers for all commanders at the end of each of the three phases of each of the four combat scenarios.

Planning quality (P), itself, was measured by summing, and then averaging for the team, the seven-point Likert scale observer evaluations of five items comprising the quality of performance of the stages of the OODA Loop planning cycle: observation, orientation, decisionmaking, execution, and overall planning and plan execution performance.

Finally, the **combat Effectiveness (E)** of the warfighting team for each time phase derives from the JTLS wargame simulator tally of the loss exchange ratio of warfighting platforms for the time phase, red losses/ red plus blue plus neutral losses. (Hiniker, 1991; Hiniker and Entin, 1992)

During the experiment all teams operated as "edge organizations" in that command was relatively decentralized, team member interactions were relatively unconstrained, and information was broadly distributed. What differentiated the teams was the technology they used. Four, three- man joint warfighting teams prosecuted the Operation Storm Petrel scenario during 16 counter-balanced trials conducted in February 2006 as a Limited Objective Experiment (LOE) at the JFCOM Joint Systems Integration Command laboratory under three different **technology treatment conditions:**

- In the **C2 Baseline treatment condition**, all three military players shared the same GCCS COP view of the Gulf and communicated via CHAT, using the current intelligence product obtained under current time lines. This is the technology suite with which most of our players had years of operational experience.
- In the new **NCW treatment condition**, the airman received track and intel data injects, including Satellite imagery, C2 common services tailored to air Community of Practice, and the two sea captains received track and intel data injects and C2 common services tailored to maritime Community of Practice, and all jointly collaborated in combat using a common LCW with drawing functionality and with simulated VOIP and joined Operational Context with stated Commander's Intent forming a common Community of Action. Here all communications for the distributed team, including Operation Storm Petrel web portal access, information

searches, and simulator and operational data base updates, were conducted over a broadband wide area network.

- In the **UDOP plus GCCS treatment condition**, both technologies were used.

A Complex Adaptive Systems (CAS) View of NCW and Experiment Hypotheses

It is useful to conceive of the warfighting team, either distributed or local, as a CAS. UDOP and CollabTech provide shared schema for the warfighting team, i.e. shared representations inside the warfighting team of the relevant external environment. (Hiniker, 2001; Hiniker, 2002) These shared representations or schema provide the CAS with descriptions, predictions, and prescriptions for effective interactions in the environment. (Gell-Mann, 1997) The UDOP represents the current situation; and the LCW permits shared graphic representation of future planned situations. Such informational schema, representing the relevant aspects of the situation and what to do about it, form the major portion of the relevant message traffic passed around the communications system, and taken together these messages constitute replicas of the state of the command decision process, itself. (See Girard, 1990) For the most part, in this "information world", observations and assessments come in and go up; plans and directives come down and go out.

The shared schema when internalized by human warfighters constitute shared mental models (Rouse and Morris, 1986), and should enable the warfighting team, conceived of as a unified CAS, to complete the group OODA (Observe-Orient-Decide-Act) Loop process more rapidly and effectively leading to greater combat effectiveness. UDOP schema should mainly aid SA; LCW schema should mainly aid Planning activities. (See Figure 1 below)

Since the informational schema are shared as mental models by human warfighters, their effectiveness is, of course, subject to the human constraints of bounded rationality, analogous to the channel capacity constraints on the speed of information transmission over a network: Performance impairing information overload can and does occur at both the psychological and informational levels of a socio-technical system. (Levis et al, 1987; Hiniker, 2001, 2002) At the "ground truth" level of the physical world, as well, human

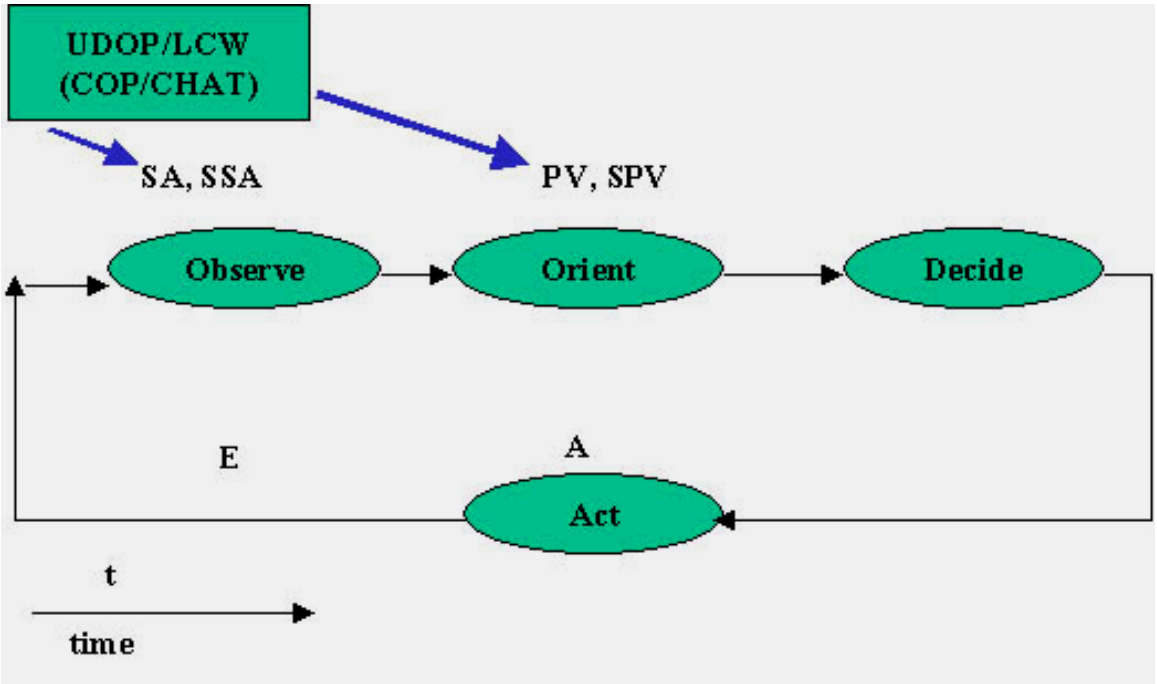
actors, sensors, weapons platforms, communications networks, and associated software and data bases can and do become impaired in the course of warfare.

Thus the interactions of the CAS with its environment entail both linear and non-linear relationships. Human information overload is an instance of a non-linear relationship in that a small positive change in informational workload near the crash threshold results in a very large degradation in performance. The connectivity of the communications network linking the warfighters in the CAS may provide other examples of non-linearity. Most network interactions involving humans are not simple random network interactions; rather they usually involve "small world" nets including shortcuts or "scale free" nets including hubs and may, under certain conditions, exhibit non-linear "percolation effects" (Moffat and Atkinson, 2005)

Here the focus will be upon the existence, rather than the form, of causal relationships between a warfighting team's use of shared schema and the consequent effectiveness of their operations in the battle space. Several causal hypotheses regarding expected empirical relationships are proposed below.

Figure 1. Group OODA Loop Process

Shared NCW Schema



Hypothesis 1 (H1). By facilitating the development of more accurate and more complete shared mental models, use of UDOP/Collab Tech by a warfighting team causes significant improvement in their Situational Awareness (SA). (See Hiniker & Entin, 1990). This effect should be amplified in scenarios in which the assessment is highly uncertain, i.e. situations in which there are many ambiguous fast moving tracks of potential mission relevance. The tailored expert views afforded by UDOP coupled with the broader channel for team communication provided by LCW coupled with audio should help mitigate the information overload when compared with use of the baseline COP/CHAT technology.

Hypothesis 1A (H1A). By facilitating group consensus on the important and relevant weapons platforms in the situation, use of UDOP/Collab Tech by a warfighting team causes significant improvement in Shared Situation Awareness (SSA) across the team..

Hypothesis 2 (H2). By facilitating group consensus, use of UDOP/Collab Tech by a warfighting team increases the quality or desirability of their developed Plan (P).

Hypothesis 3 (H3). This, in turn, increases the synchronicity of the warfighting team's action (A), leading to greater Combat Effectiveness (E).

Viewed as a whole, use of UDOP/Collab Tech should increase the speed with which the warfighting team typically completes the OODA Loop (t_d), also leading to greater Combat Effectiveness (E). (See Appendix for measurement definitions of terms)

Results. The analysis of the results of hypothesis testing in this experiment utilizes the techniques of Analysis of Variance (ANOVA), following a within subjects design, to determine whether or not use of the UDOP/CollabTech technology enabled the warfighting teams to perform significantly more effectively on the NCW performance metrics examined when compared to their use of the baseline technologies. Use of these

quantitative performance metrics also permits one to estimate the values of the NCW parameters exhibited by the warfighting teams, under each of the treatment conditions. In addition to these objective performance measures, subjective evaluations by the participants of the two sets of technologies were also solicited and analyzed.

H1: *Use of UDOP/CollabTech by a warfighting team causes significant improvement in their situational awareness.* As shown in Figure 2 below, there is no general significant increase is situational awareness due to a particular technology across all time phases of the experiment. The baseline COP affords a respectable, .35 - .40 SA measure throughout all three phases of the scenario. As shown in the Figure, the COP baseline is significantly exceeded in warfighter Situational Awareness by the UDOP+COP combination, but only during the Stage Setting and End Game phases of the scenario, ($p < .06$). During the Stage Setting phase, the UDOP+COP combination exceeded the warfighers' baseline Situational Awareness by 18%; during the End Game phase it exceeded the baseline by 12%. There was no such discernable superiority of the UDOP + COP combination during the Replanning phase.

Figure 2. Team Situational Awareness by Scenario Time Phases for Technology Treatment Conditions.

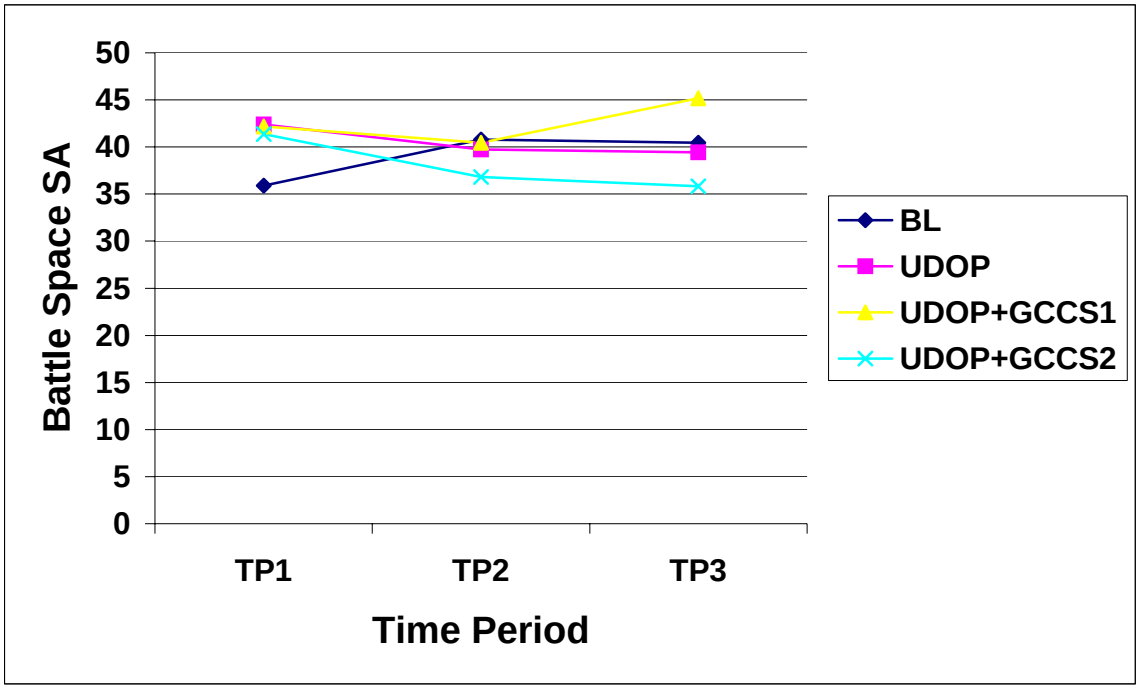
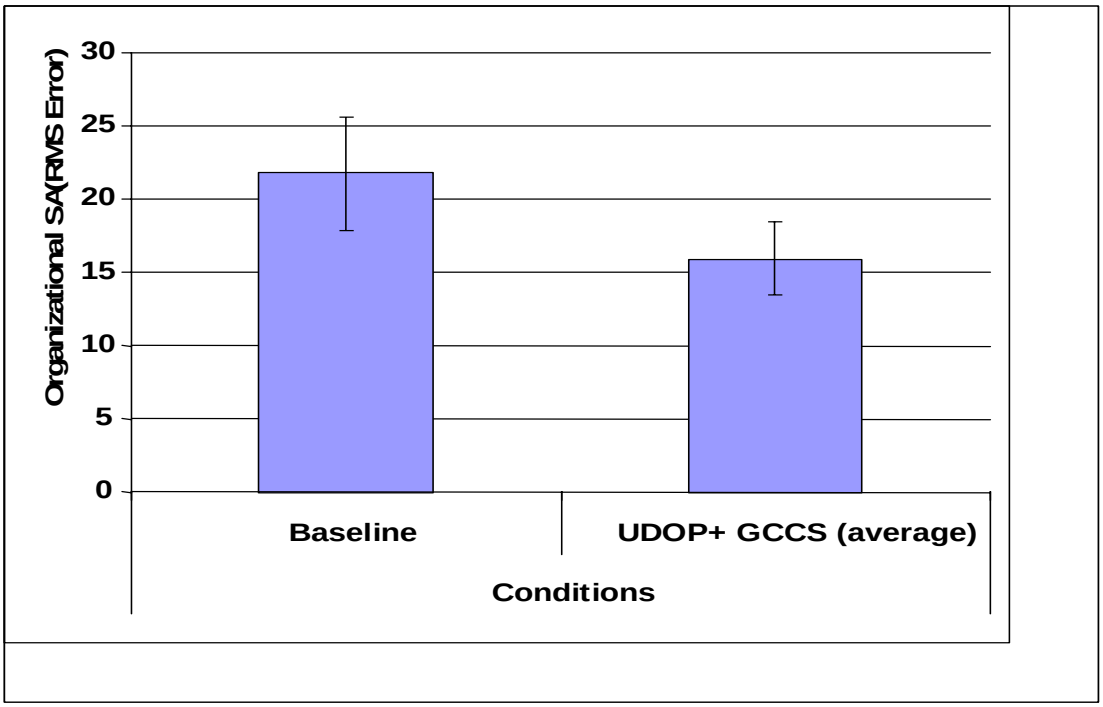


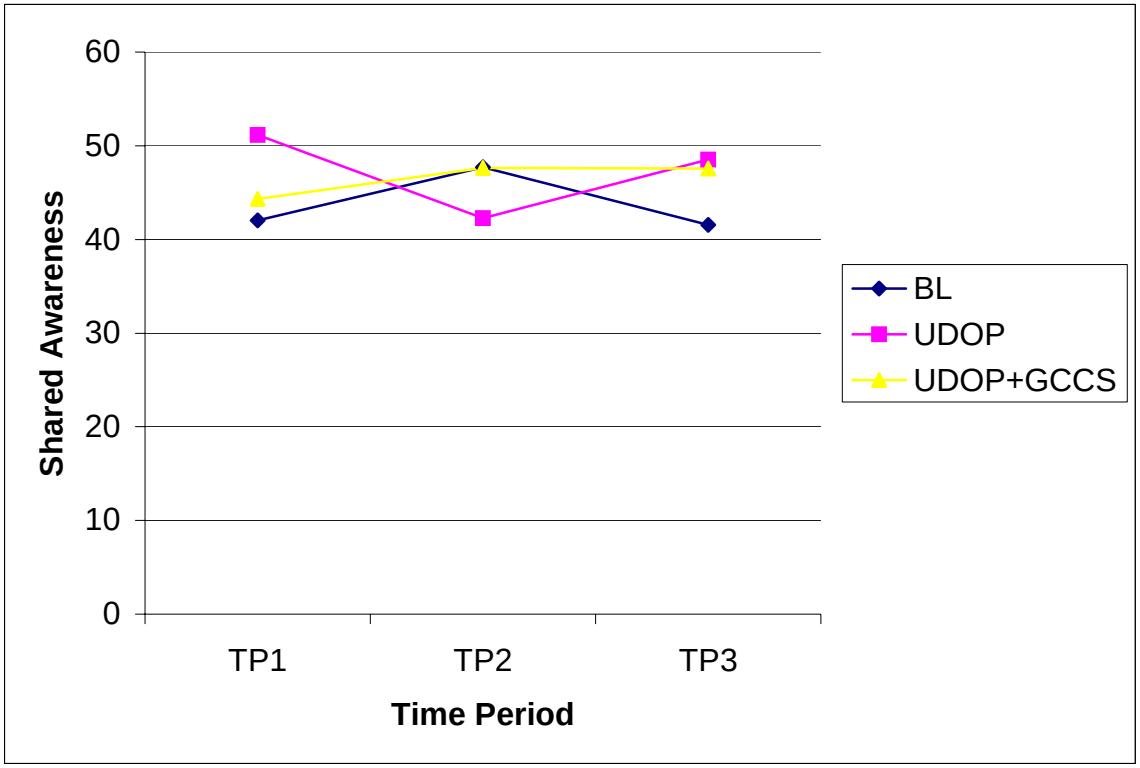
Figure 3 below depicts information that yields a possible rationale for the lack of superiority of UDOP during the Replanning phase of the scenario: As a part of the team building process, the warfighters were preoccupied with another dimension of situational awareness, viz. organizational situational awareness. In addition to battlespace Situational Awareness regarding the identities, locations and status of relevant weapons platforms, accurate knowledge of the activities of one's own teammates is another important combat consideration. (See Entin, 2002) The Figure shows that during the Replanning phase of the scenario, and only during this phase, the warfighters made significantly fewer errors in estimating the current workloads of each of their team mates when using UDOP. ($t(33) = 1.70$, $p < .05$). Team building takes attention.

Figure 3. Organizational Situational Awareness during Replanning Phase by Technology Treatment Conditions



H1A: *Use of UDOP/CollabTech by a warfighting team causes significant improvement in their Shared Situational Awareness*. As shown in Figure 4 below, UDOP significantly exceeds the COP baseline in the Stage Setting and End Game phases of the scenario, ($p < .05$). The teams using UDOP exceeded the teams' baseline Shared Situational Awareness by 22% during the Stage Setting phase; and during the End Game phase they exceeded the Shared Situational Awareness of the baseline teams by 17% . UDOP Shared Situational Awareness does not exceed the baseline in the Replanning phase. Once again, it appears that the combat team members using UDOP may have been preoccupied with the enhanced organizational situational awareness they were acquiring during the Replanning phase. Concentration on particular roles and sectors of responsibility, as opposed to the entire battle space, during this particular busy phase may have detracted from the warfighter teams' SSA scores.

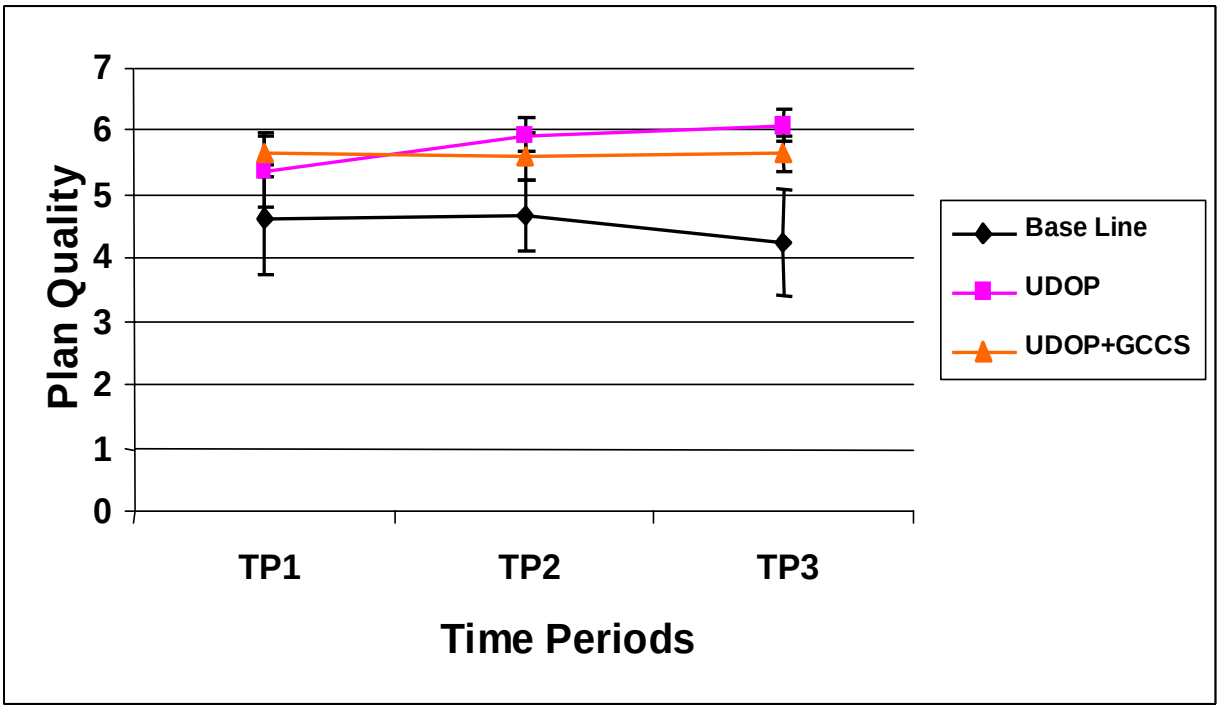
Figure 4. Shared Situational Awareness by Scenario Time Phase for Technology Treatment Conditions



H2: *Use of UDOP/CollabTech by a warfighting team causes significant improvement in the quality of the plans they develop.* As shown in Figure 5 below when the teams were using UDOP/ CollabTech they were significantly more effective in the quality of the warfighting plans they produced than when they were when using the baseline technology, throughout all phases of the scenario. ($p < .05$).

The warfighting teams using any form of UDOP exceeded the Planning quality of the teams using the baseline technology by roughly 20% throughout all three phases of the scenario. For the time periods following required replanning, TP2 and TP3, the warfighters using UDOP, itself, exceeded their planning performance using the baseline COP by 34 %.

Figure 5. Planning Quality by Scenario Time Phase for Technology Treatment Conditions

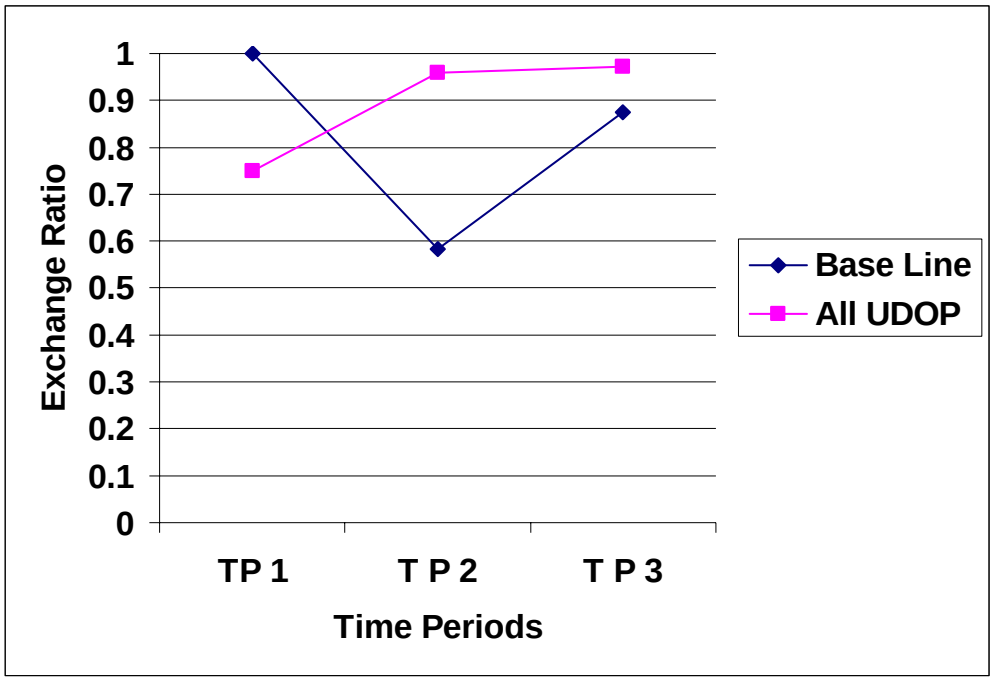


H3: *Use of UDOP/CollabTech by a warfighting team leads to greater combat effectiveness*. As shown in Figure 6 below, when using UDOP/CollabTech the warfighting teams significantly exceeded their combat Effectiveness with the baseline technology during the Replanning phase of the scenario, and moderately exceeded their combat Effectiveness using the baseline technology during the End Game phase. ($p < .05$).

Whereas the warfighter combat Effectiveness with the UDOP fell a significant 25% below their performance with the baseline COP during the Stage Setting phase, they outperformed the baseline by 64% during the Replanning phase and again exceeded the baseline by 12% during the End Game phase. It would appear that the team members' long operational experience with the baseline COP technology enabled them to fight well during the more conventional initial Stage Setting phase until replanning was required to accommodate the surprise moves by red in the later phases; then the warfighter using the

baseline technology displayed real difficulties in composing effective combat actions. When using the new UDOP/CollabTech tools, the team members appeared to take longer to get their act together, but once they did it was a significantly more effective act.

Figure 6. Combat Exchange Ratio by Scenario Time Phase for Technology Treatment Condition



In summary, close examination of all our significant findings over time reveals a consistent pattern of facts strongly favoring UDOP/CollabTech over the current COP/CHAT Baseline technology, especially for the warfighting teams' replanning opthreads. The CAS Model led us to expect that the shared schema afforded the warfighting team by UDOP/CollabTech are internalized by the players as superior shared mental models which, besides enabling greater team performance and teamwork throughout our warfighting scenario, should also lead to greater Situational Awareness, Shared Situational Awareness, Planning quality and bottom line combat Effectiveness through various phases of the dynamic warfighting scenario. The warfighers playing out our Operation Storm Petrel scenario all had much prior operational experience with the baseline COP and its associated standard CONOPS; and they were all unfamiliar with the new UDOP/Collab Tech or any associated CONOPS. They played out this time

compressed scenario in three 20 minute time phases, Stage Setting and Initial Ops (TP1); Replanning (TP2); and End Game (TP3), both with the baseline technology and with UDOP or some combination of UDOP with COP. Let us examine the significant facts emerging from this controlled experiment with warfighters.

Throughout all phases of the scenario the warfighters performed better as warfighting teams when using UDOP: they significantly exceeded the baseline COP condition on both team performance ($p = .02$) and teamwork metrics ($p < .01$).

During Stage Setting and Initial Ops (TP1), using UDOP (or some combination of technology including UDOP) the warfighting teams significantly out performed the teams using the baseline COP in Situational Awareness and Shared Situational Awareness; but when using baseline COP they significantly out performed UDOP in the initial combat Exchange ratio. This is the only time UDOP was anywhere significantly out performed by warfighters using the baseline COP technology on any of our metrics. It appears that the experienced warfighters followed the Standard Operating Procedures they were previously trained in during their initial effective combat actions at the beginning of a new scenario using the COP, and that they were delayed in their combat actions at the beginning of a new scenario when using the new procedures and additional set ups required by the new UDOP technology.

During the Replanning Phase (TP2), using UDOP the warfighting teams significantly out performed their use of the COP in quality of Planning and on the combat Exchange ratio. In this phase their Situational Awareness and Shared Situational Awareness were not significantly better than when using the COP, but they showed significantly better organizational Situational Awareness, i.e. they were significantly better in estimating the workloads of their teammates. It appears that action oriented team building somewhat distracted the limited attention of the players when using UDOP and temporarily prevented them from achieving greater battlespace Situational Awareness during this busy phase. Furthermore, it would seem that the increased assignment of special roles and sectors of responsibility accompanying this phase when using the collaborative

UDOP tool temporarily diminished their Shared Situational Awareness advantage here too.

During the End Game Phase, the warfighting teams using UDOP again significantly out performed the COP users in Situational Awareness, Shared Situational Awareness, and Planning quality, and slightly, but not significantly, out performed the COP users on the combat Exchange ratio here too.

On balance, UDOP/Collab Tech showed itself to be the superior warfighting technology for the teams throughout the three phases of the scenario, and clearly showed itself to be the superior technology following forced replanning by red. To argue the opposite, that the COP baseline technology showed itself to be the superior warfighting technology in this controlled experiment, would be very difficult, indeed, given the several significant positive NCW performance results favoring UDOP/CollabTech.

If one focuses upon the Replanning and End Game phases of the scenario, one finds strong correlational evidence for the positive impact of warfighter use of the collaborative UDOP technology upon the simulated combat outcomes and some evidence for how the technology causes this impact. The context provided by the distributed group OODA loop view suggests that team use of Shared Schema, such as the COP, cause increases in Situational Awareness; and UDOP/CollabTech Schema also cause increases in Plan quality for the warfighting team. Greater SA and greater PQ then cause increases in the combat Effectiveness of the equipped warfighting team, conceived of as a Complex Adaptive System. There is substantial empirical support for the validity of such a causal model. There is already evidence from an earlier controlled experiment with warfighters that the COP schema (included in the UDOP) causes increased combat Effectiveness: Results of the experiment at MITRE in 1992 showed that use of the COP prototype, versus local tactical pictures, yielded a 25% advantage for blue in combat Effectiveness (Y = .68 cf. .54, p = .04) (Hiniker & Entin, 1992) . In addition, an earlier controlled experiment with warfighters provided evidence supporting the proposition that COP usage causes increased Situational Awareness: Results of the experiment at Naval Oceans System Center in 1990 showed that use of the COP prototype, versus local tactical pictures, by a warfighting team yielded a 12% advantage for blue in Situational Awareness (Y = .56 cf. .50, p = .02) (Hiniker and Entin, 1990) Furthermore it seems obvious, although formally untested, that greater Situational Awareness causes increased combat Effectiveness.

In the current experiment, the correlation between collaborative UDOP use and the average combat Exchange ratio for the two phases is .54 (SEE = .17, p= .032 for 16 trials). Similarly, the correlation between use of collaborative UDOP and Planning quality is .64 (p = .004). While one must be cautious when interpreting correlations of variables across observational units that are not independent of each other, these correlational findings, as well as the more conclusive results of our ANOVA, are consistent with the proposition that use of the collaborative UDOP causes both better planning and greater combat effectiveness. However since the correlation between Planning quality and the combat Exchange ratio is only .36 (p = .086), the partial

correlation between use of the collaborative UDOP and the combat Exchange ratio controlling for Plan quality drops .11 points to .43, but remains significant ($p = .055$). There is even stronger evidence from another controlled experiment with warfighers that improved planning quality causes greater combat effectiveness: Results of the contingency planning experiment at the Naval Postgraduate School in 1988 showed that use of multi-option planning, versus single-thread planning, by a warfighting team resulted in a 16 % advantage for blue in terms of attrition of red forces per kilometer of advance (Y = 26 cf. 22, $p < .01$; effect size = 4.35/10.6 = .41) (TTCP, 2006). Thus a substantial part of the significant impact of use of the collaborative UDOP upon the combat Exchange ratio is via the causal mechanism of the improved Planning it enables, but much of the collaborative UDOP's impact on the combat Exchange ratio arrives via other avenues.

There are several other avenues of impact of the collaborative UDOP on combat Effectiveness. Besides increasing Situational Awareness and Planning quality as mechanisms to improve combat Effectiveness, the collaborative UDOP improved some other group processes that should also lead to improved combat Effectiveness, viz. team performance and teamwork. Measures of these group processes were collected by our trained observers and yielded significant results deriving from use of the collaborative UDOP. The main tech condition effect on team performance was significant ($F = 9.21$, $p < .02$; effect size = .61). The main tech condition effect on teamwork was also strongly significant ($F = 8.40$, $p < .01$; effect size = .55). Thus the collaborative UDOP creates better performing warfighting teams than the baseline technology. It remains to be determined just how much these two group process measures directly impact combatEffectiveness.

Warfighter Opinion. The dozen warfighters, and one substitute player, who participated in this experiment were very experienced with use of the baseline technology: three quarters of them had prior operational experience with the COP, one claimed more than a decades worth! Nevertheless the majority of these experienced warfighters were quite receptive to the new NCW technology as indicated by their opinions expressed on the JDCAT survey instrument. When asked "With regards to the plans that were generated (using UDOP/CollabTech) which best describes their quality?" 54% were positive and 23% were negative. When asked "Which of the following best describes your experience with network centric capabilities (UDOP/CollabTech) as compared to the COP (baseline)?" 39% were positive and 30% were negative. By way of behavioral validation of the meaning of a positive answer to this particular question we discovered a significant positive correlations of .50 ($p = .05$) between expression of a positive opinion in favor of UDOP and the degree of Situational Awareness previously attained by the warfighter in the UDOP or UDOP+GCCS treatment conditions; whereas the correlation between this opinion and the degree of Situational Awareness previously attained by the warfighter in the COP baseline condition was not significant. Here one finds some important validation for the JDCAT measuring instrument: Improved combat performance by a warfighter using a particular technology appears to cause a better opinion of that technology to be expressed by the warfighter on JDCAT.

Conclusions. In this controlled HITL experiment new NCW technology was introduced to a dozen experienced warfighters in the form of a collaborative User Defined Operational Picture enabled by a wide area network as a possible improvement on current baseline technology in the form of the Common Operational Picture with CHAT capability. Despite many years of prior experience with this baseline technology, across several phases of the Operation Storm Petrel scenario the warfighters showed significant improvements on NCW performance metrics of Situational Awareness, Shared Situational Awareness, and combat Effectiveness when using the new technology as compared to their performance with the more familiar baseline technology. The important role of enhanced Planning quality enabled by UDOP/CollabTech suggests it as a NCW metric that warrants more scrutiny. The superior combat Effectiveness of the

UDOP/CollabTech and its linkage to combat Effectiveness through improved Planning quality were especially prominent in the scenario time phases following forced replanning. Besides performing better with the new technology, the majority of the participating warfighters were also more positive in their subjective assessments of its utility.

Viewed in a broader context, this experiment is one in a long series of controlled experiments with warfighters that have supported the evolutionary development of some key DISA engineered information technologies. Thus the baseline condition in the current experiment, a GCCS Common Operational Picture with CHAT, had served previously as the advanced technology condition in an earlier controlled experiment with a similar scenario and set-up in which the earlier baseline condition had local tactical pictures located at the two ship captain posts and a big-picture Gulf view located at the remote team leaders command post. This earlier experiment discovered significantly higher Situational Awareness in the (GCCS) COP condition (Δ 12 %, $p = .02$, (Hiniker & Entin, 1990)); and replications of the experiment found significantly higher combat Exchange ratios favoring the COP condition (Δ 25%, $p = .04$, (Hiniker & Entin, 1992)). These increments in Situational Awareness and combat Effectiveness represent significant technology improvement deltas (Δ). The current experiment has employed a similar scenario, set-up, and metrics to examine the question of whether or not we have evolved another significant increment in the capability of defense technology for the warfighter over the intervening decade with the collaborative UDOP. During the Stage Setting and post-Replanning phases of the Operation Storm Petrel scenario, warfighters using the collaborative UDOP exceeded their performance with the current COP/CHAT baseline by an increment of Δ 15 %, ($p=.06$) in Situational Awareness and during the Replanning and post-Replanning phases warfighters using the collaborative UDOP exceeded their performance using the COP/CHAT baseline technology by an increment of Δ 38%, ($p < .05$) on the combat Exchange ratio. The magnitudes of these new increments approximately equal or surpass the increments by which the prototype COP/CHAT technology exceeded the local tactical pictures baseline during the past decade. (See TTCP, 2006).

The positive experimental evidence for the contention that the collaborative UDOP prototype represents a significant increment in defense capability for the warfighter is compelling. The prominent role of significantly enhanced Planning quality afforded by this new technology is noteworthy. What is especially remarkable over the intervening decade is the extent to which the information contributing to enhanced situational awareness and enhanced planning quality for the warfighter can be, and is being, transmitted over increasingly broader band, wider area networks. Given this pervasive new phenomenon, one might ask how large a CAS is it feasible to construct, with warfighters sharing sensors, schema, weapons, and feedback over the network, with our new technology in the future. New research should answer this question, but it seems likely that the major limiting factor will not be our technology but ourselves.

APPENDIX

Measurement Definitions for UDOP/LCW Situational Awareness Delta LOE

- **Situational Awareness (SA)** = Proportion of mission critical set of warfighting platforms correctly identified by a warfighter (Ground Truth cf. COG @ t_i)

- **Shared Situational Awareness (SSA)** = Proportion of overlap between pairs of COGs for complete warfighting team.

- **Plan Quality (P)** = Accuracy of knowledge of scheduled sequence of blue moves.

- **Speed of Command** ($\mathbf{t_d} = t_c + t_r + t_a + t_b$), where total speed of command is the sum of time to size up situation + time to plan + time to act + time to complete decision cycle with battle damage assessment

- **Combat Effectiveness (E)** = Loss/Exchange Ratio= red platform losses / (red + blue + neutral losses)

- **Subjective Opinion of Operational Value of Technology** = Participants' scoring on seven point Likert scale.

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