Revisiting “SCUDHunt” and the Human Dimension of NCW: Some Thoughts

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Abstract

The “SCUDHunt” game-based experiments conducted by the CNA Corporation and ThoughtLink Inc during 2000–2002 explored Shared Situational Awareness (SSA) in a Network Centric Warfare (NCW) environment. Our paper re-analyses the results of those experiments, with a particular focus on the human dimension of the experimental results. We thereby significantly extend the conclusions of the original study, which was focused on technology issues rather than the human dimension. Our re-analysis demonstrates that differences between “good” and “bad” teams had a greater impact on mission effectiveness than any technology factor. It also shows that major contributors to mission effectiveness were good team dynamics, professional mastery, and ability to use the technology. Of these, team dynamics was the most important. Our re-analysis also illustrates the fact that the often lauded Shared Situational Awareness (SSA) is not an end in itself: poor teamwork and insufficient levels of professional mastery can lead to teams sharing agreement on incorrect assessments of the situation, sometimes with tragic results. Our conclusions underline the importance of the human element in the networked future force, and support the Australian emphasis on professional mastery. We conclude with some general observations and lessons learnt in the area of human experimentation for NCW.

1 Introduction

Following the work of Alberts, Garstka & Stein (1999), Network Centric Warfare (NCW) has been strongly endorsed by Defence Forces in the US, Europe, and also in Australia (“Force 2020,” 2002; “Enabling Future War Fighting,” 2004), albeit with some criticism and calls for refinement of the concept (Lambert & Scholz, 2005; Giffin & Reid, 2003; Reid & Giffin, 2003).

NCW is defined by Alberts, Garstka & Stein (1999) as “… *an information superiority-enabled concept of operations that generates increased combat power by networking sensors, decision makers, and shooters to achieve shared awareness, increased speed of command, higher tempo of operations, greater lethality, increased survivability, and a degree of self-synchronization. In essence, NCW translates information superiority into combat power by effectively linking knowledgeable entities in the battlespace.*”

The four fundamental assumptions or tenets of NCW in US doctrine are as follows (Alberts, 2002), and are illustrated in Figure 1:

1. A robustly networked force improves information sharing.
2. Information sharing and collaboration enhance the quality of information and shared situational awareness.
3. Shared situational awareness enables self-synchronization.
4. These, in turn, dramatically increase mission effectiveness.

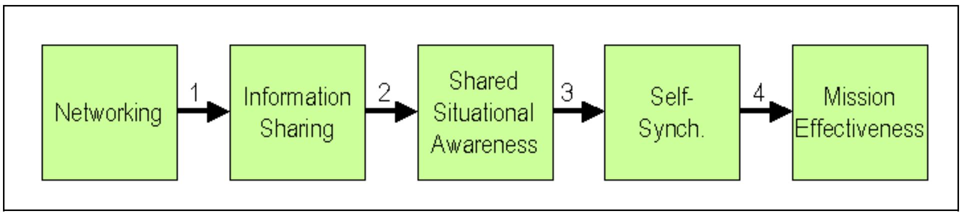

Figure 1: Network-Centric Warfare tenet chain

In Australian NCW doctrine, two additional tenets are added ("Enabling Future War Fighting," 2004), which have a supporting role rather than being part of the chain in Figure 1:

5. Professional mastery is essential to NCW.
6. Mission command will remain an effective command philosophy into the future.

Professional mastery is defined in Australian doctrine to be "*… an expression of how individuals apply their skills, knowledge and attitudes to the task at hand … developed through training, education and experience*" ("Enabling Future War Fighting," 2004). Mission Command (Lind, 1985) is an effective command strategy going back to Guderian (1952), which "*promotes flexibility and individual initiative*" ("Enabling Future War Fighting," 2004).

By revisiting a series of experiments conducted in 2000–2002 using the "SCUDHunt" game, we will show that the human dimension of NCW is potentially more important than the technology dimension, and that these additional tenets (or some generalisations of them) are critically important for the success of NCW. Further tenets relating to the human dimension may also be needed.

2 SCUDHunt

The "SCUDHunt" game-based experiments conducted by the CNA Corporation and ThoughtLink Inc during 2000–2002 explored the middle part of the NCW tenet chain: Shared Situational Awareness (SSA), and particularly how technology can improve this (Perla, Markowitz, Nofi, Weuve, Loughran & Stahl, 2000; Loughran, Stahl & Perla, 2001; Stahl & Loughran, 2002; ThoughtLink, 2003). Simple and elegant, the SCUDHunt game nevertheless challenged experienced military personnel, and therefore collected data that continues to provide useful insights into the implementation of NCW. The game involves locating three stationary "SCUD" missile launchers hidden on a 5×5 game board. A distributed team of four players attempts to locate the missile launchers using information-gathering assets of different kinds:

Player 1 – Space Asset Manager:

- Reconnaissance satellite

Player 2 – Air Asset Manager:

- Manned aircraft (may produce false positives)
- UAV (can be shot down)

Player 3 – Intelligence Manager:

- Communications Intelligence (can be fooled by deception operations)
- Human Intelligence (reliable, but highly limited)

Player 4 – Special Operations Manager:

- Joint Special Operations (need to be inserted and extracted)
- Navy SEALS (can be inserted via coastline only)

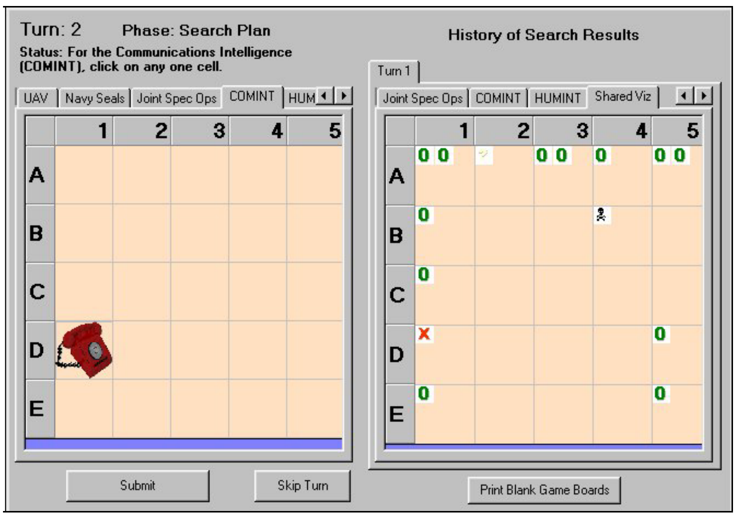

Figure 2: Snapshot of SCUDHunt game (ThoughtLink, 2003)

The left side of Figure 2 shows a snapshot of the SCUDHunt game software (ThoughtLink, 2003), with the Intelligence Manager focusing Communications Intelligence efforts on square D1.

Team members playing the SCUDHunt game need to work together to collect information and then make a group decision on SCUD locations. Figure 3 shows an example conversation between team members playing SCUDHunt (Stahl & Loughran, 2002), and Figure 4 shows the SCUDHunt game process.

Space Player:	SPACE to col. 3.
Spec Ops Player:	With your assets up to the ne, I can send the seals across to D2 and joint spec ops up to d5
Spec Ops Player:	Both spec ops will be within search range of E3/E4
Air Player:	Maybe spec ops can clear out row E. I'll take manned air over row A and the uav down col 4 so that next space pass will give us corroboration
Spec Ops Player:	I could send the seals down to E2 vs D2 next, but both air and space had e2 clean
Spec Ops Player:	Air, are you thinking Joint Spec ops to E4 this round vs D5
Space Player:	What is level of conf that INTEL is right about E5 (that SEALs chickened out?)?
Air Player:	Yes, because you can always move to D5 on a diagonal, right?
Intel Player:	Where is Joint Spec ops starting from? Can they do E4 this turn and D5 next?
Intel Player:	Comint is VERY good at saying a space is Clear
Spec Ops Player:	Yes to intel, they start back in E5. the Koronans ability to hide scuds is low, I think Joint Spec Ops hit that low probability of koronan security with no scud.
Spec Ops Player:	So seals to D2, Joint Spec Ops to E4 this rnd.
Space Player:	Concur.
Air Player:	Sounds good
Intel Player:	6 of one, half dozen of another

Figure 3: Sample SCUDHunt team conversation transcript (Stahl & Loughran, 2002)

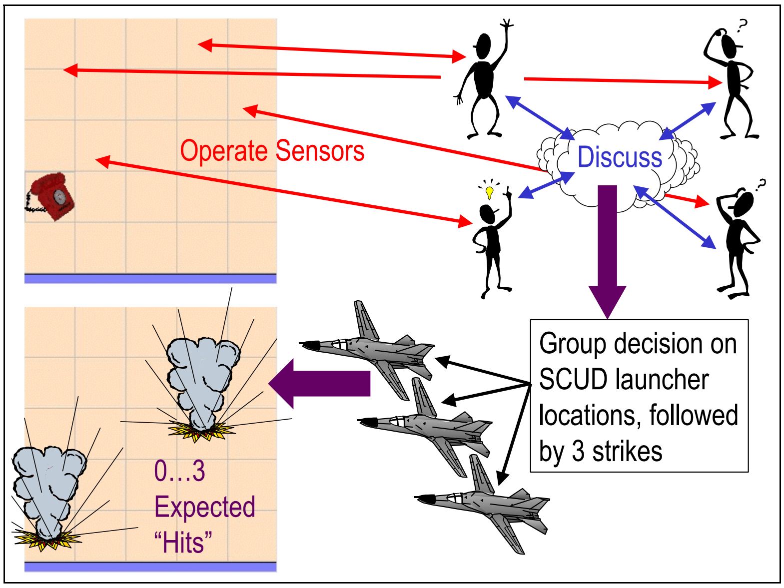

Figure 4: SCUDHunt game process

3 Experiment 1

The first SCUDHunt experiment, conducted in 2000, involved six teams, including high school and junior high school students, as well as adults (Perla, Markowitz, Nofi, Weuve, Loughran & Stahl, 2000; Loughran, Stahl & Perla, 2001). Each team played six games, with a different combination of collaboration technologies in each game, and with each team trying the different technology combinations in a different order. A Latin Square experimental design was used, and the experiment trialled three kinds of collaboration tools:

- voice chat (telephone);
- text chat; and
- a “shared visualisation” tool.

The shared visualisation tool is shown on the right of Figure 2, and provides a combined view of the data collected by all players. On the surface, such a tool seems of great benefit, although in practice it did not increase performance beyond that of voice or text chat. Performance with these tools was compared against performance with no communication between team members, i.e. with each team member predicting SCUD locations based only on his own intelligence assets.

Published results for this experiment concentrated mostly on how the technology influenced Shared Situational Awareness (SSA), but perhaps more interesting are the mission effectiveness scores. In this experiment, mission effectiveness was measured by the expected number of SCUD launchers destroyed, if three air strikes were made at the locations recommended by the team (assuming the air strikes were totally successful). We have re-analysed the experimental data that was collected on mission effectiveness, summarised in Table 1. The data in Table 1 is classified according to team, and whether one or more of the collaboration technologies was made available.

Table 1: Mission effectiveness scores for experiment 1, by team

Team	Expected number of SCUDs destroyed (0…3)		
	One or more technologies	No collab. technologies	Overall
T1	2.4	1.1	2.2
T2 (poor leader)	2.3	0	1.9
T3	2.5	0.5	2.1
T4	2.6	1.5	2.4
T5 (students)	1.7	0	1.4
T6 (junior students)	0.7	0	0.6
Average	2.0	0.5	1.8

The effect of having some form of collaboration technology was naturally extremely statistically significant (with the probability that the results were due to random chance being $p < 0.00001$ by Analysis of Variance), since without any collaboration technology, the team could not collaborate. However, the experiment did not show any statistically significant difference between the different kinds of technology ($p = 0.89$). Table 2 shows the averages for the difference combinations of collaboration technology trialled. The slight variation in these results can only be attributed to random effects – all three forms of technology seem to be of equal value. The original report on this experiment suggested that perhaps “*the nature of the SCUDHunt game and experiment created a situation in which the information conveyed through the shared visualization tool and through the text and voice communications had a high degree of overlap*” (Loughran, Stahl & Perla, 2001, p. 3).

Table 2: Mission effectiveness scores for experiment 1, by technology

Technology	Expected number of SCUDs destroyed (0–3)
Voice chat alone	2.2
Text chat alone	2.1
Shared Visualisation alone	1.9
Shared Visualisation & Voice	2.0
Shared Visualisation & Text	1.9
Average	2.0

The differences between the six teams were also statistically very significant ($p < 0.0002$). The student teams performed particularly poorly, as did Team 2, where the Space Asset Manager acted as team leader in spite of making poorer guesses on SCUD locations than anyone else in his team (Loughran, Stahl & Perla, 2001, p. 34).

This reflects an issue famously raised by Kruger and Dunning (1999): "… *when people are incompetent in the strategies they adopt to achieve success and satisfaction, they suffer a dual burden: Not only do they reach erroneous conclusions and make unfortunate choices, but their incompetence robs them of the ability to realize it.*"

This phenomenon creates a significant problem when the individual with incomplete awareness is an authoritarian team leader. It becomes even more of a problem in cultures with high "power distance," where people feel greater pressure to agree with authority figures (Hofstede, 1980; Heacox, Gwynne, Kelly & Sander, 2000). During the Falklands/Malvinas War, the authoritarian Argentinian military culture compromised effectiveness and contributed to the eventual British victory (Stewart, 1991). Well-designed computer-based collaboration systems do offer the opportunity to reduce this effect, and make it easier for team members to present their point of view (Sproull & Kiesler, 1991). The use of Mission Command (Lind, 1985) also helps to reduce this problem, by giving subordinates authority to carry out their missions using the means which seem best.

Analysis of Variance of the experimental data shows that 39% of the variation in the results is due to team differences, 31% due to the presence or absence of collaboration technology, and the remaining 30% due to random effects. In other words, the differences between teams had a greater impact on mission effectiveness than any of the technologies. This has an important implication for NCW: should the introduction of NCW divert attention away from the personal selection and training needed to create effective military teams, then it could well prove to be a disadvantage.

4 Experiment 2

Some light can be shed on issues involving effective military teams by re-examining SCUDHunt data collected in an experiment at the US Naval War College (NWC) in 2002 (Stahl & Loughran, 2002). Again, team effectiveness was not the focus of the original experiment, but the excellent experimental design allowed a re-analysis of the results to be conducted in a similar way to the previous experiment.

Table 3: Professional mastery levels for SCUDHunt experiment 2

Professional Mastery Level	NCOs	Officers
4	 E4 (2)	No Degree (0)
5	 E5 (1)	
6	 E6 (1)	Bachelors Degree (3)
7	 E7 (5)	
8		Masters Degree (8)
9	 E9 (3)	
10		PhD (1)
Total Personnel	12	12

This experiment involved six teams of military personnel, half officers, and half NCOs. There was no statistically significant performance difference between the two groups ($p = 0.77$). Given the Australian NCW tenets, we were interested in the effect of professional mastery on military effectiveness. Since only limited data about people was collected in the original experiment, we measured professional mastery for NCOs using simply rank. For the officers (who were mostly at the O5 level), we used the highest level of educational qualification obtained (encoded to have a distribution of numbers similar to NCO ranks). Table 3 shows the numbers of people in each category.

Players were also asked two questions about technology skills:

- "Please rate your level of expertise with text chat on a 1…7 scale" and
- "Please rate your level of computer skill on a 1…7 scale"

Averaging the answers to these two questions provided a simple measure of technology mastery.

Data for this experiment was collected slightly differently from the previous experiment, and in our re-analysis, we focused on the average accuracy of each individual's guesses about SCUD locations. As in the first experiment, the biggest differences were between teams, as shown in Table 4. Even when members of the team did not agree, they often benefited from discussions with other team members. Between-team differences in accuracy scores were statistically significant ($p < 0.01$). Also noticeable was the fact that players on some teams had a very large difference between their average accuracy scores. In other words, they came to radically different assessments on where the SCUDs were located. This is evidence that these teams were not functioning properly, and hence we use the standard deviation ("spread") of results within a team as an indirect measure of team failure.

Table 4: Team breakdown and results for experiment 2

Team	Average Age	Ave. Technology Mastery Level	Average Player Accuracy	Standard Deviation
T1 (officers)	45	4.2	57%	18%
T2 (E7/E7/E7/E9)	42	4.4	83%	3%
T3 (officers)	39	3.3	68%	6%
T4 (E4/E4/E5/E6)	27	5.2	60%	9%
T5 (E7/E7/E9/E9)	44	4.4	55%	15%
T6 (officers)	48	5.4	78%	2%
Average	41	4.4	67%	

The data does not permit any definite assessment as to why certain teams failed. Anecdotally, team T2 appeared to succeed because all players knew each other well, and had developed a winning strategy during practice sessions of the game (Stahl & Loughran, 2002, p. 14). Team T6, composed of reservist officers, also worked together extremely well. One player on team T6 was able to apply prior experience from analogous problems in mine detection and clearance (Stahl & Loughran, 2002, p. 16).

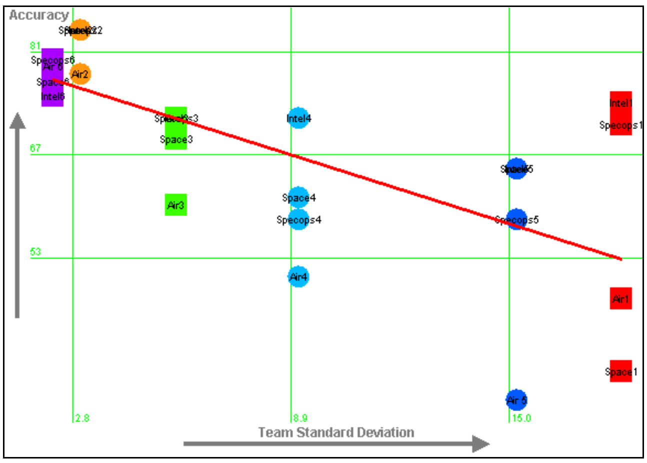

Figure 5: Effect of team "spread" on player accuracy for experiment 2

The standard deviation ("spread") of results within a team predicted 45% of the variation in individual player's accuracy scores, as shown in Figure 5 (officers in this graph are denoted by squares, and NCOs by circles, while the vertical and horizontal lines show mean and standard deviation). This effect was statistically very significant

($p < 0.0004$), and the ability of players to work together as a team had a greater impact on performance than any other factor. Naturally, a large “spread” of results means that the average score must be poor, although if player scores were random, that would not imply a correlation with team “spread.” What is important is that teams which agreed with each other (teams with a low “spread,” at the left of Figure 5) did well. That is to say, their agreement was correct. As we shall see in Section 5, this is not always the case. It would, of course, be desirable to repeat the experiment with a more direct measure of team failure than just the “spread” of results, in order to confirm this finding.

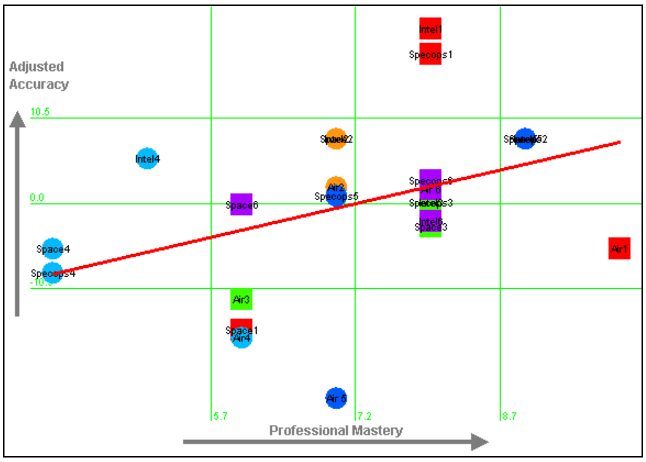

Figure 6: Effect of professional mastery levels on adjusted accuracy for experiment 2

Adjusting the results for the team effects, the professional mastery levels in Table 3 predicted an additional 9% of the variation in player’s accuracy scores, as shown in Figure 6. This effect was statistically moderately significant ($p < 0.06$), since it only involved aspects of professional mastery not related to teamwork (aspects such as the analogy with mine detection and clearance described above). In a re-analysis such as presented here, such a level of significance should naturally be treated with some caution, and it would be desirable to repeat this study with an experiment specifically designed for studying teamwork and other human factors. In games more closely resembling real military operations, we would expect the effect of professional mastery to be greater than the 9% found here.

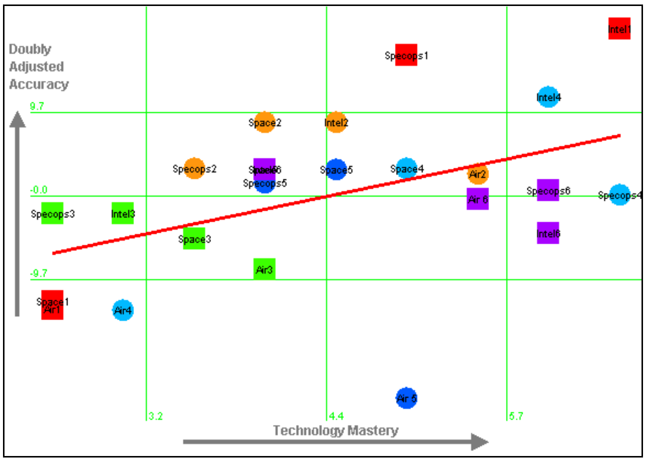

Figure 7: Effect of technology mastery levels on doubly adjusted accuracy for experiment 2

Adjusting the results for both team effects and professional mastery levels, the technology mastery levels (based on the two questions about technology skills) predicted a further 9% of the variation in player’s accuracy scores, as shown in Figure 7. This effect was statistically moderately significant ($p < 0.03$), since the SCUDHunt game software was not particularly difficult to use (although team T3, with the lowest technology mastery levels, did experience difficulty using the software).

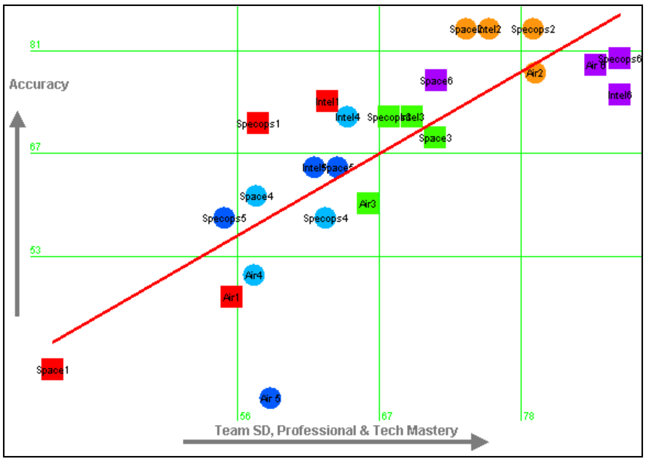

Figure 8: Effect of all three factors on player accuracy for experiment 2

Figure 8 shows the prediction of player accuracy scores *A*, using a multiple regression on all three factors (team "spread" *S*, professional mastery *P*, and technology mastery *T*):

$$A \approx 39 - 1.58\,S + 3.6\,P + 3.7\,T \qquad (1)$$

This combined regression predicted 63% of the variance in player accuracy scores (a correlation of 0.80), with 37% of the variance due to unknown or random factors. Since most of the variance is accounted for, we can have some confidence that professional mastery, technology skills, and, most of all, teamwork are the main drivers for mission effectiveness in this kind of networked team environment. This lends support to Australia's inclusion of professional mastery within the NCW tenets ("Enabling Future War Fighting," 2004), as well as highlighting the need for improving teamwork. It is generally accepted that mission command is associated with improved teamwork, although work remains to be done on establishing this linkage formally (Lambert & Scholz, 2005).

Player ages had no additional effect on performance ($p = 0.47$), i.e. there was no support for the idea that younger personnel have an advantage in this kind of computer-based teamwork. Indeed, in the first experiment, younger players were at a significant disadvantage. This is probably because the two key factors of professional mastery and teamwork are both developed with increasing maturity.

5 Shared Situational Awareness *vs* Mission Effectiveness

Returning to Experiment 1, our re-analysis examined factors determining mission effectiveness, while the original analysis (Perla, Markowitz, Nofi, Weuve, Loughran & Stahl, 2000; Loughran, Stahl & Perla, 2001) considered Shared Situation Awareness (SSA), as measured by agreement between team members on where they thought SCUDs were located. How does SSA relate to mission effectiveness?

NCW tenets 3 and 4 suggest that increasing SSA will improve mission effectiveness. Figure 9, a refinement of a graph in the original analysis (Loughran, Stahl & Perla, 2001, p. 20), shows that 64% of the variance in mission effectiveness was indeed due to SSA (a correlation of 0.80).

Squares in Figure 9 show results for the three poorly-performing teams (T2, T5, and T6) and circles results for the three better teams (T1, T3, and T4). Figure 9 shows clearly that the three poorly-performing teams had poorer mission effectiveness then would have been predicted based on their SSA scores, and this is statistically extremely significant ($p < 0.00001$). That is to say, the three poorly-performing teams failed partly because they came to incorrect shared agreements about SCUD locations.

Shared Situational Awareness (SSA) is thus not an end in itself: poor teamwork and insufficient levels of professional mastery can lead to teams agreeing on incorrect assessments of the situation and on incorrect courses of action. Without adequate training of military personnel, networking technology runs the risk of reinforcing such incorrect agreements, rather than reinforcing desirable self-synchronisation.

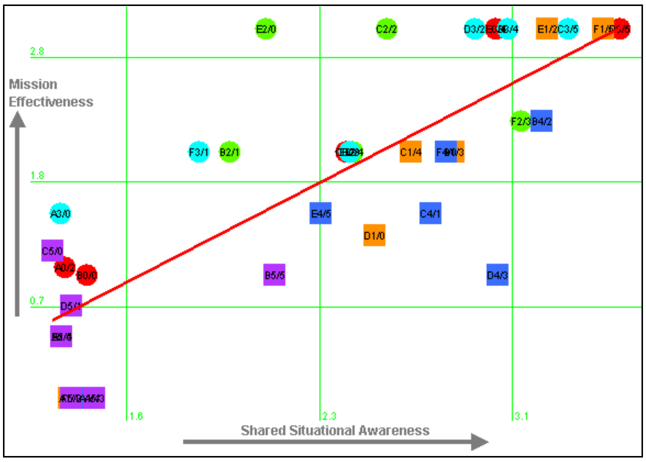

Figure 9: Mission effectiveness predicted by SSA for experiment 1

A tragic example of incorrect SSA was the shooting down of Iran Air Flight 655 by the USS Vincennes on 3 July 1988 (Fogarty, 1988). The problems involved in classifying an incoming air track, such as occurred on that day, are similar to those raised by the SCUDHunt game. In both cases, different kinds of information of varying reliability must be combined to give situation awareness – and in such situations, providing more information does not necessarily improve decision-making (Omodei, Wearing, McLennan, Elliott & Clancy, 2004). Also in both cases, performance is affected by the tools available, the level of training of personnel, and team dynamics. However, in real operations, the stakes are higher than in a simple computer game, and incorrect situation awareness can have far more serious results.

6 Discussion

In this paper, we have re-analysed data from the 2000–2002 "SCUDHunt" experiments, which examined the performance of networked teams in a simple military-inspired scenario, in order to shed light on the tenets of NCW. Re-examining data from the first SCUDHunt experiment demonstrated that differences between "good" and "bad" teams had a greater impact on mission effectiveness than any technology factor. Closer examination showed that one of the characteristics of "bad" teams was incorrect agreement on the situation, i.e. agreement which did not translate into mission effectiveness (as illustrated in Figure 9).

Re-examining data from a 2002 SCUDHunt experiment at the US Naval War College provided a clearer understanding of the factors leading to good performance. These were:

- Good team dynamics, indicated by a narrow "spread" of accuracy scores within a team, and responsible for 45% of the variation in performance (although a better measure of team dynamics would be desirable for future experiments).

- Professional mastery, as measured by rank for NCOs and formal qualifications for officers, and responsible for 9% of the variation in performance.

- Technology mastery, as measured by self-assessment of skill with computers and text chat, and responsible for 9% of the variation in performance.

The importance of team dynamics and professional mastery in this experiment provides some justification for the two additional tenets which Australia has added to NCW doctrine:

- Professional mastery is essential to NCW.
- Mission command will remain an effective command philosophy into the future.

It would be beneficial to confirm the results of our re-analysis with an experiment specifically designed to study team issues. In particular, better measures of team dynamics would be desirable.

Further work also remains to be done on the relationship between mission command and effective teamwork (Lambert & Scholz, 2005). However, the re-analysis which we have conducted supports Australian doctrine on the importance of the Human Dimension (“Force 2020,” 2002, p. 6):

“*It is not technology, systems or platforms that generate the real capabilities for our Defence Force, it is the strength of our* ***people****. The power of Australia’s Defence Force has always been the quality of its members. We have a history of achievement and excellence, which provides a firm foundation for our current activities as well as those of the future. However, this foundation may be eroded if we do not give our people the high priority they deserve.*”

7 Some Reflections

Reflecting on the re-analysis that we have conducted, there are a number of valuable lessons which we have learned. The SCUDHunt experiments (Perla, Markowitz, Nofi, Weuve, Loughran & Stahl, 2000; Loughran, Stahl & Perla, 2001; Stahl & Loughran, 2002; ThoughtLink, 2003) were some of the best-designed in the study of the human dimension of NCW, and future work in this area should build on the strengths of these experiments, while avoiding their weaknesses.

One key lesson learned was the benefit of collecting as much data as feasible about the experimental subjects, since it is not always possible to predict in advance which variables will be useful for later analysis. Many variables (such as age for the experiments reported here) are important in that they can be checked and ruled out as significant factors.

Human beings are highly variable, and experiments with human beings are faced with the perpetual problem of finding a pattern which stands out from this variability in a statistically significant way. Several past NCW experiments have failed to deliver statistically significant results. There are two methods for achieving statistically significant results:

- having a very large number of experimental subjects (usually infeasible); and
- careful experimental design, such as the Latin Square used in SCUDHunt.

The factors under investigation must be as clear as possible, in order to stand out from human variability. For example, SCUDHunt was designed so that communication between team-members was critically important to success in the game, as demonstrated by Table 1. This made SCUDHunt an ideal instrument for studying team behaviour, since poor team dynamics had a significant effect on performance. Other games for studying team behaviour should also be designed in such a way that it is impossible (or at least very difficult) to “win” without cooperating. However, SCUDHunt was too simple to be able to distinguish differences between voice, text, and visual communication (Table 2). The simplicity of the game meant that the quantity of information needing to be transmitted between players was fairly small, and hence none of the available communication channels were overloaded.

Some factors determining success are clearest in the presence of time pressure. Certain kinds of communication technology act to speed up or slow down communication (Sproull & Kiesler 1991) and hence influence the chance of finishing a task within a given time limit. However, trial and error are often necessary to determine the best time limit to use.

In a game-based experiment, the game must generally be easy to learn. If players are still learning the game during the experiments, learning effects may obscure the results. On the other hand, if learning effects are the focus of study, the game must be sufficiently complex so that players continue learning during the course of the experiment.

It is important that experiments be designed with analysis techniques in mind. If data is collected without any thought for future analysis, then that analysis will be difficult, if not impossible. Even the kind of re-analysis we have presented here is dependent on a good initial experimental design.

Our re-analysis has also underlined the importance of visual analysis techniques, such as the graph in Figure 9, in parallel with statistical techniques such as Analysis of Variance (ANOVA) and regression. Visual analysis, particularly the use of colour and shape, can make it much easier to find patterns in the data.

A more specific observation is that there is a need for better theoretical structures, metrics, and experimental instruments for evaluating team dynamics. The lack of these was a limiting factor for our re-analysis, and the observations made by David Alberts (Alberts, 2002) remain true:

"*How teams work is a subject that has received some attention, but little of it has been focused in military domains with the pressures inherent in these situations. … We need to know far more than we currently do about this behavior so that we can better focus our experiments and determine the ranges of expected team performance. … Work needs to be done to identify the various forms of collaboration, understand their characteristics, and relate them to military tasks and situations. … Cross-cultural collaborations present a unique set of challenges that must be better understood.*"

In current work, we are using modelling and simulation to help understand structural factors determining team performance.

8 Acknowledgements

Thanks are due to Michael Markowitz (CNA) for the original SCUDHunt game design; to Peter Perla (CNA) for the excellent original experimental design; to Julia Loughran and Marcy Stahl (ThoughtLink) for further development of SCUDHunt and for making experimental data available; to Stephen Downes-Martin (NWC) for making experimental data available; and to the above and to Albert Nofi (CNA), Christopher Weuve (CNA), Jon Cecchetti (NWC), Robert Rubel (NWC), Gina Kingston (DSTO), Robert Mun (DSTO), and Leoni Warne (DSTO) for discussions on NCW.

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