12th INTERNATIONAL COMMAND AND CONTROL RESEARCH AND TECHNOLOGY SYMPOSIUM

Adapting C2 to the 21st Century

NCW in Action - Experimentation within A Distributed and Integrated Command Environment (DICE)

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Abstract

DICE is a concept of enabling distributed and dynamic operations in the battlefield by virtue of a distributed yet integrated command environment. Such a command environment would be able to support not only traditional hierarchical commands, as well as enable a flattened force structure where the edge elements, that is, the disparate fighting units, are empowered with the information they need as well as the authority to collaborate and self-synchronize in the effective execution of distributed and dynamic operations as they adapt to the changing battlespace. A 'live' Limited Objective Experiment was conducted by the Singapore Armed Forces (SAF) in November 2006 in the Shoalwater Bay Training Area in Queensland, Australia, to evaluate the feasibility of the DICE concept in supporting an edge organization employing mission command. The experimentation measurement framework of success indicators is categorized into the following areas: network-enabled, operation awareness, team collaboration, self-synchronization, and decision responsiveness. These emergent characteristics collectively lead to successful distributed and dynamic operations in response to the changing battlefield environment. This paper describes the experimentation measurement framework and method in detail, and examines the results of the Limited Objective Experiment as an example of an application of the DICE measurement framework.

Topics: Network-centric warfare, Edge Organization, Experiment Measurement Framework

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Introduction

A plethora of books and papers have been written about Network-Centric Warfare (NCW) in the Information Age. NCW proposes a shift from the traditional military hierarchical command philosophy to a structure where forces are more nimble and operate on networks to increase their shared awareness as well as to self-synchronise with one another. However, while the concept of NCW is nothing new, it has existed for many years now as just that – a concept more than a real operational capability. Alberts et al (1999) point out that the translation of the NCW concept into a real operational capability requires more than the implementation of information technology and networks. They define a Mission Capability Package comprising concepts of operation, C2 approaches, organisational forms, doctrine, force structure, support services, and the like that is required to leverage information superiority in the realisation of NCW. This paper aims to present the Singapore Armed Forces Centre for Military Experimentation's (SCME) effort towards the development of a Distributed and Integrated Command Environment (DICE) concept, as well as a specific MCP made possible by DICE.

DICE is a concept that enables forces to work distributed and be agile and flexible to deal with the complexity of military and/or civil-military operations in the world today. DICE proposes a command environment that would allow the Commanders or the organization to adopt not only the traditional military hierarchical command philosophy, but also a force structure where the edge elements, that is, the disparate fighting units, are empowered with the information they need as well as the authority to collaborate and self-synchronize in the effective execution of distributed and dynamic operations as they adapt to the changing battlespace. The two command philosophies i.e. the strict hierarchical command method for detailed control and co-ordination vis-à-vis intent-driven mission command where edge units are able to self-synchronise with other edge-units and the headquarters through networks, can co-exist simultaneously or sequentially through the different phases of an operation, based upon the mission and situation at hand. The key element in DICE is the ability to support a continuum of processes for these C2 models as characterized, thereby allowing Commanders to switch between models with relative ease in accordance to the situation at hand.

SCME conducted a Limited Objective Experiment (LOE) in November 2006 to evaluate the feasibility of the DICE concept in supporting an edge organization employing mission command. The Mission Capability Package explored was the operational context of dynamic heliborne operations. In our design and development of this LOE, we have also come to realise the need for a measurement framework to guide our assessment and evaluation in our experimentation efforts of the capabilities afforded by DICE. As such, we have developed an initial version of a measurement framework for the experimentation of DICE under the conditions of C2 structure, process, and model that we have chosen, which we would like to put forth as one that would be useful in other similar experimentation of NCW concepts. The remainder of this paper describes the measurement framework we have developed, followed by the LOE in dynamic heliborne operations conducted in November 2006, as an example of an application of the DICE measurement framework.

A Measurement Framework for DICE

Alberts and Hayes (2006) describe the value chain of a network-centric enterprise in which robust networking is expected to lead to information sharing and collaboration, which will consequently improve both individual and shared awareness. That, in turn, is expected to improve decision-making and also enable self-synchronization if the C2 model permits. The desired outcome is a dramatic improvement in mission/enterprise effectiveness and agility.

Figure 1 illustrates the theoretical framework developed for the experimentation of DICE within the SAF based on the value chain proposed by Alberts and Hayes (2006). This presents the first version of a measurement framework that would guide experimentation efforts as we seek to develop and eventually incorporate the concepts made possible by a Distributed and Integrated Command Environment for the SAF. Admittedly, this measurement framework is amenable to being expanded upon as our experiences with DICE mature. Nonetheless, it is instructive to describe this first iteration of the framework here.

We believe that it is important to first characterise the underlying network, as it is a critical factor in the performance of command teams under the different organisational structures made possible by the DICE concept. We have adopted Albert and Hayes' (2003) framework for describing the degree of connectivity achieved in the information domain, as put forth in their book titled *Power to the Edge,* which covers the areas of reach, richness, and characterization of interactions. A further breakdown and description of the various dimensions comprising each category is detailed in the section on the experiment measures.

With a robust network in place, Gompert et al (2006) argue that the networking power should be harnessed to generate cognitive advantages. They suggest that a network can be thought of in three ways: (1) as a *distributor* of information to individual minds; (2) as a *mobilizer* of many minds; and (3) as a *venue* for collective thinking. Accordingly, the cognitive advantages that may be derived from networks include (1) improving the individual's sensemaking of distributed information; (2) empowering more people with the authority to make decisions; and (3) fostering and harnessing the power of collective intelligence.

With these cognitive goals in mind, the next level that our framework addresses is that of the process of individual sensemaking, defined as "the integration of relevant military experience and expertise with real-time battlespace knowledge to generate individual awareness and understanding" (Alberts and Hayes, 2002). We have borrowed from Endsley's (1995) model of situation awareness in thinking about an individual's operation awareness at different levels, in terms of a basic perception of the situation, an understanding of the implications, as well as a projection of future states of the battlespace. While we have adopted Endsley's model of situation awareness, we have however also realized that the Situation Awareness Global Assessment Technique (SAGAT) that she puts forth may not be suited for all types of experimentation, so we have had to devise alternate techniques that seek to probe the levels of operation awareness in a way that suits our specific experiment. More on this is detailed in the section on the experiment method and measures.

We next address the social domain of team collaboration and self-synchronization, which corresponds to Gompert et al's articulation of collective intelligence and devolved decision-making. This level of team cognition and decision-making clearly requires communication among the warfighters. We have thus adopted an analysis of the communication stream among the experiment participants at an intermediate level of detail that incorporates both semantic and quantitative aspects as an indicator of team collaboration and self-synchronization. This method of analysis was put forth by Entin and Entin (2001), and looks at the absolute number as well as ratio of transfers versus requests for information, action, and coordination. More details on this are given in the section on experiment measures.

The highest level of our framework addresses the desired outcome of all the preceding characterizations in the information, cognitive, and social domains. One of the key goals of having a Distributed and Integrated Command Environment is such that the command team can be nimble in adapting to the evolving battlespace in order to change its structure, command philosophy and behavior continually in a way to increase its success. Such a change, however, must be mediated such that it would not incur more confusion to the fighting forces. Grisogono (2005) puts forth in her treatment of Complex Adaptive Systems that the property of being adaptive requires, among other things, "some way of evaluating the impact of a variation on the system's fitness – generally achieved through some kind of *interaction and feedback*". We believe that the underlying networks of the DICE concept and the associated emergent properties of individual sensemaking, team collaboration and self-synchronization together put in place the infrastructure for continual sensing and feedback that is essential to any effective adaptive mechanism. We have also adopted Grisogono's classification of adaptive mechanisms based on the time-scale and effects-scale over which they operate. These may be summarized as follows: responsiveness (fast and local); resilience (fast and local up to major); agility (intermediate, major and/or wide-ranging); flexibility (slow, major and wide-ranging).

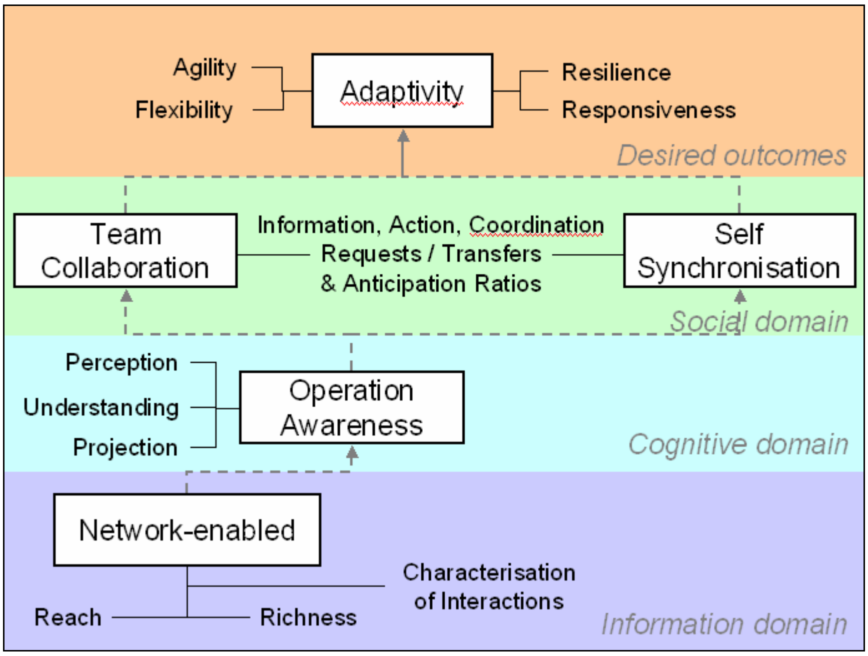


Figure 1: DICE experimentation measurement framework.

The Experiment

A series of 'live' field trials were conducted by the Singapore Armed Forces (SAF) in November 2006 in the Shoalwater Bay Training Area in Queensland, Australia. These trials constituted a LOE of the DICE concept, with a focus on getting networked warfighters to synchronize their own actions in a relatively flat command hierarchy in the context of dynamic heliborne operations. The remainder of this paper describes the experiment method as an example of an application of the DICE experimentation measurement framework, as well as the results obtained, along with a brief discussion of these.

Participants

The participants comprised a composite team of up to 28 Air Force and Army officers. Four Air Force officers were each assigned to play the role of a helicopter jump-seat pilot in each trial. There was some minor variation in the nominal roll of the participants across each trial run, but the same roles were played in each trial. The experiment participants could not be the actual pilots or co-pilots of the helicopters due to operational safety considerations, thus these relatively junior helicopter pilots were tasked to play the role of jump-seat pilots.

The Army officers who participated in Runs 1 and 2 were fairly junior Army officers who role-played a heliborne Battalion that was to be airlifted into the operational theatre. However, the Army participants in Run 3 were in fact an operational heliborne Battalion involved in a full-troop exercise. The Brigade Commander at the Forward Command Post also participated in Run 3.

This paper will only address the interactions between the Air Force participants (N = 4) as we were particularly interested in how the DICE concept would allow the jump-seat pilots to synchronize their own actions in an edge organization. The Army officers operated in the context of a traditional hierarchy, and while their participation provided a realistic context to the experiment, it was not the focus of this LOE.

Design

This series of trials was designed as a concept refinement experiment (Kass, 2006) of DICE in facilitating an edge organization of warfighters, with repeated measures. There was no independent variable that was tested across each trial run, as the results are to be compared to the known threshold of current operations.

The design of the trials included a formal training session for all the Air Force and Army participants on the ForceMate C2 system, as well as two dry runs or test-sessions each lasting half a day before the three actual experiment runs were conducted.

The experiment controllers comprised a senior Air Force officer who played the role of the Helicopter Planning Team (HPT), and a senior Army officer who played the role of the Battalion Commander in Runs 1 and 2. This core team of experiment controllers dictated the unfolding of the scenario for each experiment run.

The success indicators used to assess the DICE concept as well as the performance of the jump-seat pilots were identified to be (a) network-enabled, (b) operation awareness, (c) team collaboration, (d) self synchronization, and (e) decision responsiveness, as was described in the section on the DICE Measurement Framework. The measurements taken on these five main success indicators are described in detail in the following section.

Measures

The success indicators were measured using a combination of participant questionnaires, observer protocols, as well as communication logs. A description of how each success indicator was measured is given below.

- Network enabled – The degree of connectivity achieved between the various warfighters was qualitatively assessed by the observers in terms of information richness, reach, as well as the characteristics of interactions between and among the entities made possible as a result of the networks (Albert and Hayes, 2003). Information richness was assessed according to the degree of sharing of various forms of information – visual, audio, multimedia, and tools. The extent of reach was assessed along the dimensions of whether it allowed the participants to be asynchronous in space and time, whether it facilitated simultaneous, selective, and universal communication, as well as the availability of the system. Lastly, the degree of connectivity between the various warfighters was described in terms of the characteristics of the interactions that networks enabled in terms of being multi-party and interactive.
- Operation Awareness – With a networked command environment, the expectation was that the warfighters would be able to post and smart-pull the relevant information they need in order to adapt to and operate effectively within the changing environment. As operation awareness exists in the cognitive domain, participants were asked to complete questionnaires at the end of each trial to assess their awareness of the evolving battlefield situation (e.g. detected enemy units, own force operations) and their understanding of the mission demands (e.g. updated tasks, changes in plans). The respondents were also asked to rate their confidence level regarding each answer (0 being not confident at all, and 10 being very confident), as an indication of how sure they were of the evolving situation

during the trials. The questionnaires did not probe the participants' projection of future states of the battlespace, because the mission had already been completed by the time the questionnaires were administered. It was not possible to administer the questionnaire in mid-flight during the experiment run due to operational security concerns which were paramount.

- Team Collaboration – The degree and quality of collaboration between the various team members was inferred from the analysis of the text-chat log from each trial run. The text-chat messages were categorized according to the different communication types as follows:
    - Information Requests (number of requests for information, e.g. "where is the enemy location?");
    - Information Transfers (number of transmissions of information, e.g. "affirm landing point is hot");
    - Action Requests (number of requests for an action, e.g. "can you please create the route in ForceMate?");
    - Action Transfers (number of statements of actions (to be) taken, e.g. "I am planning the route for us.");
    - Coordination Requests (number of requests to coordinate an action, e.g. "copied my route? Check if there's any conflict");
    - Coordination Transfers (number of agreements to coordinate an action, e.g. "We'll need to coordinate our landing sequence… Head North, and land in sequence of helicopters 1,2,3,4");
    - Acknowledgements (number of non-substantive acknowledgements of receipt of communication, e.g. "roger");
    - Communication Check (number of non-substantive utterances to establish communication, e.g. "do you copy?");
    - Others (all other communication that do not fall into any of the above categories).

  Analysis of the communication stream was not only based on simple frequency counts of the various types of communication as listed above, but was also augmented with the anticipation ratios – a measure based on the ratio of transfers to requests – which together provide a meaningful window into the team processes.
- Self Synchronization – In the context of this experiment, we would say that self synchronization was achieved if the jump-seat pilots were able to work out the details of their actions in response to information about the external situation provided to them, without having to overly rely on the HPT to provide specific directions. A proxy measure of the degree of self synchronization that was achieved among the jump-seat pilots was derived from the analysis of the breakdown of the different types of communication attributed to the HPT as compared to each of the jump-seat pilots. The expectation is that the HPT's text chat messages would largely comprise Information Transfers, while the jump-seat pilots' communication stream would also comprise the higher order types of communication (e.g. Action/Coordination Transfers/Requests).
- Decision Responsiveness – Decision responsiveness was the only dimension of adaptivity that was explored in this experiment. It was simply measured as the time taken for the warfighters to complete the adjustment of their plans in response to injects that they received in the course of each experiment run. The times are measured from the point of administration of the inject, to the time when the adjusted plans were approved.

Scenario

The scenario used in each of the experiment runs was that of a Battalion day heliborne operation in two waves of four helicopters each, into a fictitious enemy terrain called Middleland North, for the purpose of securing and establishing Zone of Security CONGO. Each block position was to be held by a Task Force (each a Company minus), and there was another Task Force in Reserve, so as to deny the Enemy Regiment Reserves (Company plus) from reinforcing or counterattacking the enemy's Main Defence Line. Figure 2 shows the operational plan briefed to the experiment participants prior to the start of each experiment run.

Figure 2: Operational Plan prepared for each experiment run.

Table 1 describes some sample injects that were administered during each experiment run in the context of this scenario.

Inject	Description	Expected action	Purpose
1	Enemy patrol detected en route	Jump-seat pilots expected to collaborate and adjust route	Test of air-air coordination
2	Landing Points reported to be HOT	Jump-seat pilots to dynamically decide to land at alternate Landing Points within given directory. Update ground troops.	Test of air-air and air-ground coordination
3	Change of flight plans for Wave 2 issued at Pick-up Zone	Ad-hoc replanning while distributed	Test of air-air coordination
4	Landing Points reported to be HOT	Jump-seat pilots to dynamically decide to land at alternate Landing Points within given directory. Update ground troops.	Test of air-air and air-ground coordination
5	Enemy reported to be engaging Block Position	Units to be re-tasked to reinforce Block Position.	Test of ground-ground coordination

Table 1: Sample injects administered during each experiment run.

Task

The task presented to the Air Force participants was the same across all runs. The HPT would either directly issue injects to the jump-seat pilots, or trigger the actual helicopter pilots to report a sighting or an incident, so as to cause the jump-seat pilots to initiate adjustment of their flight routes and/or landing points within the overall mission assigned to them. The instruction given to the jump-seat pilots was for them to bear the heliborne Battalion's end objective in mind, and to discharge them at any of the landing points within the pre-designated directory of landing points for them to carry out the ground mission.

Command and Control System - ForceMate

The system used in the experiment was ForceMate, the concept tactical C2 system developed by the SAF Center for Military Experimentation (SCME). ForceMate is in essence a "light" implementation of the TeamSight concept (Cheah and Fong, 2006), one that is able to operate off laptop computers under field conditions. ForceMate retains the key collaborative features of the TeamSight concepts, such as allowing all the participants access to the team operational picture as well as communication via text chat. The more system intensive features like maintaining a separate workspace for each individual and communication via video-conferencing were done away with in ForceMate.

In this experiment, a key requirement was for ForceMate to facilitate collaboration among the participants despite them being distributed within the theatre of operations. ForceMate was used within and across Services (air-air, ground-ground, and air-ground) to create operation awareness, as well as to collaborate and synchronize their actions in response to the unfolding scenario. This was facilitated by the following features within ForceMate: (1) graphical map display and tactical drawings for the presentation and discussion of plans, and (2) text-chat which enabled broadcast, group, or peer-to-peer messages. Figure 3 shows a screenshot of the ForceMate system, as the participants in each run would have viewed it.

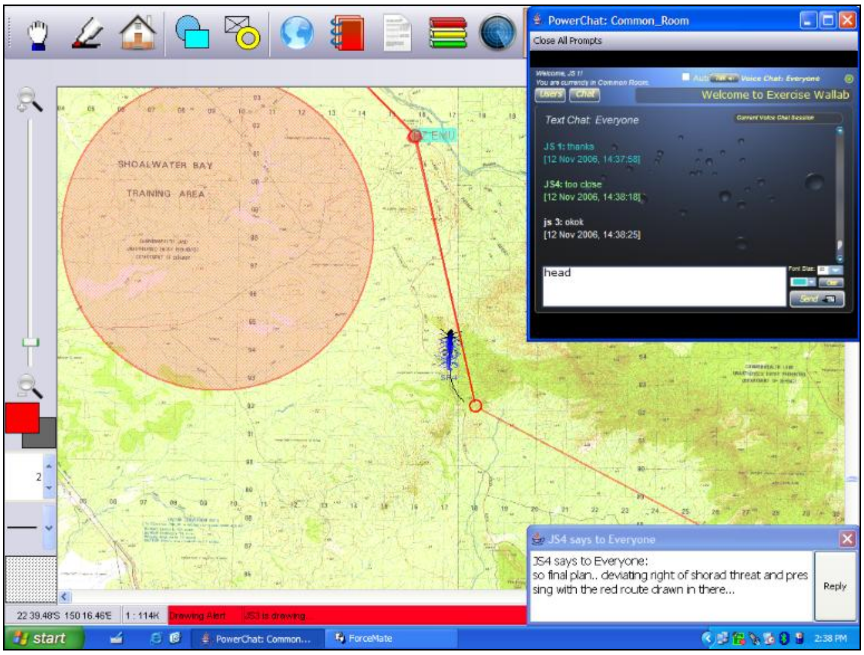


Figure 3: Screenshot of ForceMate terminal.

Procedure

Preparations. The experiment participants received 4 hours of training and hands-on practice on the ForceMate C2 system in Singapore prior to departing for Australia. They received approximately an additional 1.5 hours of re-familiarisation training in Australia prior to the experiment runs. The participants were also informed about the purpose of the experiment, and briefed on the scenario prior to Run 1. The Air Force participants were also involved in the two dry runs prior to Run 1, and these provided opportunities for them to get used to the concept of collaborating amongst themselves in an edge organisation.

Data Collection. All the experiment participants were asked to complete questionnaires at the end of each run to assess their level of operation awareness. All the text chat communication between participants in each of the runs was recorded for post-hoc analysis of team collaboration, self-synchronization, and decision responsiveness. Screenshots of the ForceMate terminals were also logged at 5-second intervals so as to enable the experiment team to correlate the text chat log with what the participants were referring to in their conversation. In addition, there was one observer on each helicopter during each of the experiment runs to take note of interactions among the jump-seat pilots, as well as their communication with the respective aircraft captains. The observers were each also given a ForceMate terminal such that he/she was privy to the on-going communication stream to help in their collection of anecdotes.

Results

Network Enabled

The degree of connectivity achieved during field experiment may be characterized as follows (refer to Figure 4 for a graphical representation):

- *Information Richness*:
    - Visual. There was a high degree of sharing of information in visual form (text, graphics and overlays, e.g. flight paths, enemy forces, deployments and activities, etc)
    - Audio. There was no voice transmission between participants through the ForceMate system. This was due to the safety-imposed employment of jump-seat pilots (as opposed to co-pilots) for the experiment. Voice transmissions by jump-seat pilots were limited to within the aircraft (i.e. intra-cockpit environment).
    - Multimedia. There was a moderate degree of multimedia information sharing (text and graphics; no video or audio).
    - Tools. There was a high degree of information richness facilitated by collaboration using a common ForceMate system available to all participants.
- *Reach*:
    - Asynchronous in Space. The participants were able to operate effectively despite being physically located in different helicopters, over an area of approximately 20 x 25 km (but subject to line of sight).
    - Asynchronous in Time. The text chat provided a form of raw history of the communications that occurred. This enabled the participants to operate asynchronously in time to a certain extent. During the experiment, the affected participant was able to use the network to get himself updated on the situation through observation and information exchange with his peers, without recourse to the HPT or Brigade Commander. However, it was difficult for a participant to catch up with the copious amounts of communication after being offline for too long. The incorporation of an indexing and search feature would probably be useful to help overcome this.
    - Simultaneity. Most of the participants were able to receive the content being shared at about the same time and to do so in a timely manner.

- Selectivity. A participant could selectively choose who to send out text messages to (broadcast to all, members within a chatroom, or peer-to-peer), depending on the content and relevance of the information.
- Universality. The network and ForceMate system enabled a high degree of universality for communications across Services (air-ground) as well as across echelons (Battalion-Company; HPT-pilots).
- Availability. Each participant had a dedicated terminal for him to access ForceMate, so availability of the system was high, as there was no competition for resources. However, as the network was not always stable, various participants would lose connectivity to the network at different times, thus limiting the reach of information sharing.

- *Characteristics of Interactions*:
  - Multi-party. Many participants could interact to solve a problem at the same time, leading to rich collaboration. During the experiment runs, we had up to 28 participants interacting through the system at any one time.
  - Interactive. There was a high degree of interactivity where participants could reciprocate to a piece of information pushed across the network.

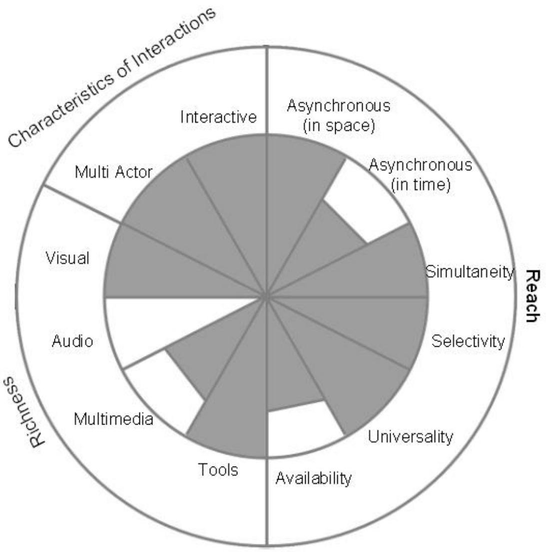


Figure 4: Depiction of the degree of connectivity achieved during the field experiment.

Operation Awareness

Table 2 shows the results of the measure of operation awareness across the various trials.

	Run 1	**Run 2**	**Run 3**
Air Group	Awareness: 75% Confidence: 9.66 / 10	Awareness: 90.6% Confidence: 9.1 / 10	Awareness: 100% Confidence: 10 / 10

Table 2: Results from survey of Operation Awareness.

The results of the Air Group across the three trials show a moderate to high level of awareness of the operational picture, as well as a high level of confidence regarding their awareness. The apparent moderate awareness in Run 1 was attributed to the fact that the jump-seat pilots were admittedly confused with the designation numbers of the Landing Sites during the actual mission.

Team Collaboration
Table 3 shows the results of analysis of the text-chat log from each trial.

	Run 1	**Run 2**	**Run 3**
No. Messages in total	438 (Broadcast)	349 (Air Group) 52 (Ground Group) 13 (Air-Ground Grp)	406 (Broadcast) 74 (Ground Group) 20 (Air-Ground Grp)
Communication Types			
Information Requests (IR)	59	54	41
Information Transfers (IT)	83	63	70
Action Requests (AR)	22	17	11
Action Transfers (AT)	52	23	20
Coordination Requests (CR)	11	7	6
Coordination Transfers (CT)	10	19	41
Acknowledgements (ACK)	83	56	82
Comms Check (CC)	60	45	26
Others (O)	58	65	109
Communication Ratios			
Overall anticipation	1.57	1.35	2.26
Information anticipation	1.41	1.17	1.71
Action anticipation	2.36	1.35	1.82

Table 3: Results from analysis of text-chat logs.

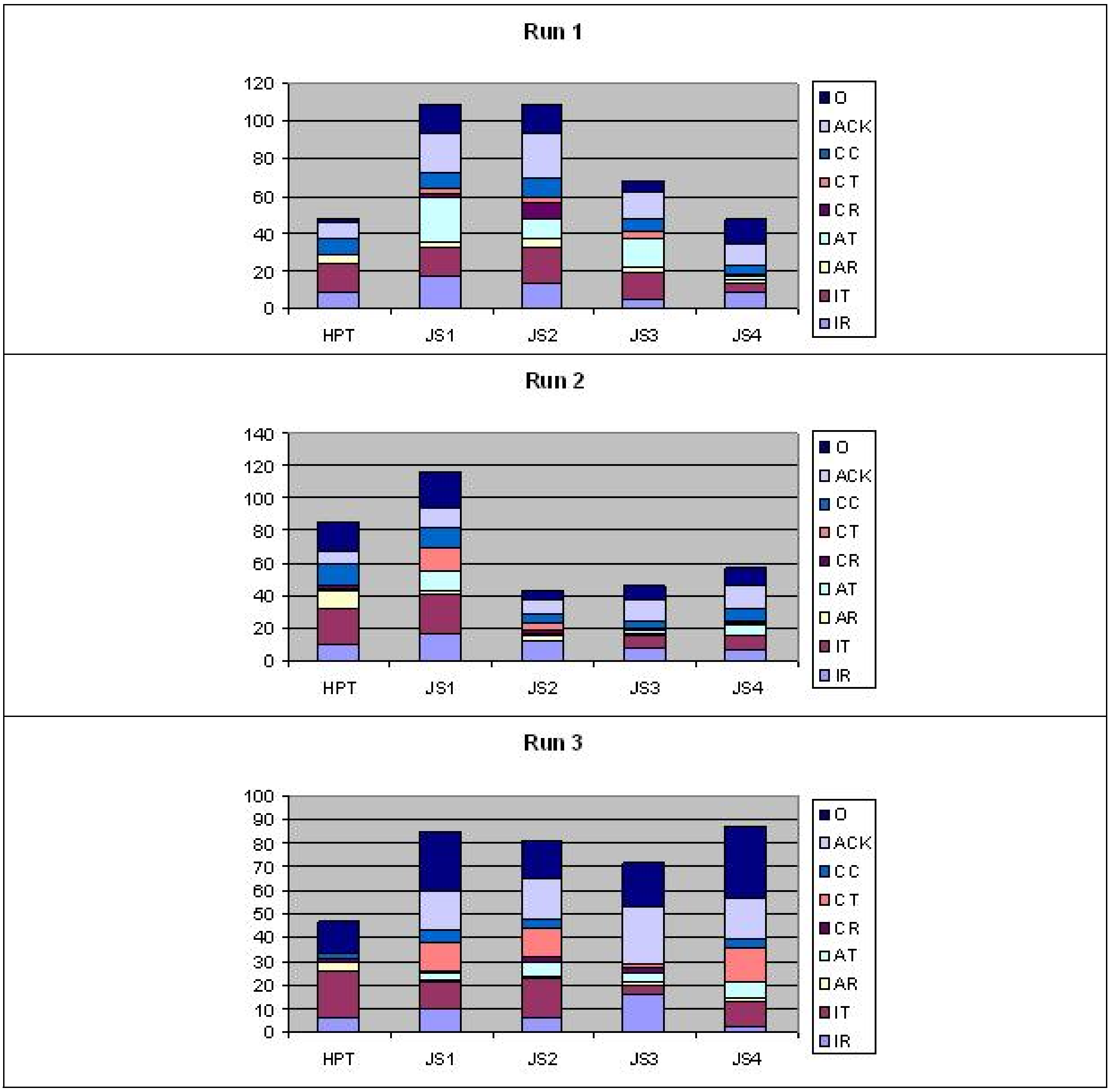
Table 3 elucidates the communication profile during each trial. The anticipation ratios are greater than 1.0, and may be taken to mean that team members were able to anticipate the information/action needs and requirements of the other members in his team and offer these before the latter requested them. This is an indication that the team was collaborating well to achieve the mission and tasks assigned to them.

Team collaboration amongst the jump-seat pilots was further enhanced by the graphical interactions facilitated by ForceMate. An average of approximately 7% of communications among the Air Group in each run specifically referred to the graphical overlays. These communications were mostly regarding the dissemination of danger areas or new/adjusted routes that would otherwise be cumbersome to describe in words and lat/long positions. For instance, the HPT informed the jump-seat pilots of enemy SHORADS as such, "SHORADS max effective range 5km detected en route to LS40. Depicted by red circle. Please inform crew and replan." The jump-seat pilots adjusted their routes on ForceMate and updated HPT as follows, "so final plan… Deviating right of SHORAD threat and pressing with red route drawn in there…" Refer to Figure 3 again for a screenshot of this particular interaction where an economy of words was achieved as a direct consequence of the rich graphical collaboration facilitated by ForceMate.

The communication profile may also be supported by anecdotal evidence that indicate that the team was able to collaborate during the trials. For instance, the HPT issued an ad hoc secondary mission for mass heli-casevac during Wave 2 in Run 2. Despite the time it took to plan for the new mission on-the-fly, the jump-seat pilots were generally able to collaborate amongst themselves the number of aircraft required for this mission, the flight path to the pick-up and drop-off points, the holding area for aircraft while waiting their turn to land, as well as the landing sequence of the helicopters. This mission would have been aborted had not for the information inputs offered by the rest of the team members to the flight lead (represented by the lead aircraft jump-seat pilot).

Self Synchronization

Figures 5 a,b,c shows the result of the breakdown of communication types per participant, across the various runs.



Figures 5 a,b,c: Breakdown of types of communication per participant in Runs 1, 2, and 3 respectively.

There are several trends that are made salient in the bar charts shown in Figures 5 a,b,c. Firstly, we see that in Run 1, the jump-seat pilots are able to self-synchronize by taking the initiative to let their team members know of the actions they are about to take, without overly relying on the HPT other than as a source of information. However, the jump-seat pilots are fairly reliant on jump-seat pilots 1 and 2 to take on the role of mission leads, as indicated by the high volume of communication of both these jump-seat pilots (approximately 110 messages each). In Run 2, the trend of relying on a lead aircraft continues, with jump-seat pilot 1 contributing approximately 120 messages. However, the composition of these 120 messages by jump-seat pilot 1 sees a notable increase in the percentage of Coordination Transfers as compared to Run 1. As a caveat, it should be noted that the network performance was severely degraded during Run 2, so the dip in the volume of communication attributed to jump-seat pilots 2-4 could perhaps be a result of that. The communication profile of Run 3 indicates that the jump-seat pilots have truly warmed up to the concept of self-synchronization. We see that the volume of communication from each of the jump-seat pilots far exceeds that of the HPT, yet they are fairly equal (between 70-80 messages each) with no one particular jump-seat pilot overly loaded. Also, jump-seat pilots 1, 2, and 4 have contributed significant amounts of Coordination Transfers as compared to previous runs.

Decision Responsiveness

Table 4 shows the time taken by the jump-seat pilots to respond to the various types of injects.

Inject description	Time taken to respond		
	Run 1	**Run 2**	**Run 3**
Enemy ADA / deployments / movements sighted. Re-routing of flight plans to avoid enemy firing template.	11 min	16 min	9 min
LZ/LS/LP reported hot / unsuitable for landing.	3 min to decide on alternate LP; another 5 min to re-plan route to new LP.	NIL	1 min to decide on alternate LP; another 2 min to re-plan route to new LP.
Ad hoc secondary mission	NIL	25 min	NIL

Table 4: Average time taken by jump-seat pilots to respond to various types of injects.

The timings shown in Table 4 reflect the possibilities given the DICE concept. The ability of the jump-seat pilots to collaborate and adjust their plans in response to the injects is in itself an improvement over the current way of doing things, which would call for the mission to be aborted in the event of unexpected occurrences developing outside of a small number of planned contingencies. Decision quality was not taken into account in this series of trials, primarily because the jump-seat pilots were relatively junior and inexperienced. Notwithstanding this, they were able to construct reasonably sound plans in response to the injects. It is expected that the timings could possibly be shorter with more senior and experienced pilots, and with voice communications available instead of solely text chat.

Discussion of Results

Given that this LOE was the first time that the SAF helicopter pilots were exposed to the use of Mission Command, having been trained for years on the process of centralized control by the HPT, jump-seat pilots were assigned to try out this new command philosophy instead of involving the actual pilots or co-pilots of the helicopters due to operational safety considerations. However, the close interactions between the jump-seat pilots and their respective aircraft captains also enabled the helicopter pilots and co-pilots to appreciate the advantages of Mission Command over a more centralized mode of control. The feedback from the participants was that they felt entrusted and empowered to make decisions regarding dynamic route (re)planning to divert from potential danger areas in a responsive manner, instead of having to always rely on the HPT and the Brigade staff. Indeed, the analysis of the data collected corroborates with the participants' feedback and points to their ability to effectively collaborate, self-synchronize and make timely decisions in response to the unfolding experiment scenario.

Another possible advantage of mission command that we observed is that it frees up the higher command (the HPT in this case) to devote his attention to other critical areas, for instance the concerns of mission assurance and survivability. This was not fully explored in the context of this LOE, but perhaps warrants more thought as to how the HPT's roles and responsibilities could perhaps be re-defined given that much of the time-consuming control functions have been taken off his hands.

There was, however, a challenge to having helicopter pilots operate under Mission Command. The issue of concern is the potentially high workload on the part of the pilots and co-pilots in the absence of the jump-seat pilots who participated in the LOE purely for experimentation purposes. However, this may be overcome by rigorous training of the pilots to be cognitively agile in dealing with these increased demands on his attention.

At the conclusion of the three runs that comprise this LOE, the pilots were tasked to fly another similar mission as part of a larger full troop exercise. Although the pilots and the air controllers reverted to the usual SAF model of centralised command and control for this mission with specific training objectives, yet it was observed that the pilots' exposure to Mission Command during the LOE had changed their mindset, and a greater sense of responsibility remained with them. They were observed to be much more aware of the potential dangers and possible contingency plans, and they were ready and eager to collaborate and self-synchronise their actions in the event that there was loss of the HPT function.

This observation is heartening, because a key element of agility is having warfighters who are primed to switch between different models of command and control. Although this was not explicitly validated in this LOE, it was at least observed in the pilots' behaviour in the very last training mission in that even while they had reverted to a model of centralised command and control, the LOE had conditioned them to consider the possible contingencies to ensure mission assurance. Indeed, mission assurance is not just about a set of processes or doctrine but about the behaviour of the team given connectivity, and how they are conditioned to collaborate and effect self-synchronisation in response to a loss of higher command.

Conclusions

This paper had set out to describe the DICE experimentation measurement framework and an application of the framework to a LOE conducted by the Singapore Armed Forces (SAF) in November 2006 in the Shoalwater Bay Training Area in Queensland, Australia. The purpose of this LOE was to refine the concept of applying DICE to facilitate collaboration and self-synchronization within an edge organization, as well as to assess the usefulness of the DICE measurement framework as applied to a real experiment. The DICE measurement framework proved to be a useful guide in the assessment and evaluation of networks in engendering the desired outcome of decision responsiveness as well as the emergent characteristics in the cognitive and social domains. The analysis of the data collected during the trials indicates that this field experiment was able to achieve moderate to high levels of success in the areas of interest identified.

Although the series of trials do not allow us to make any experimental comparisons across the various runs, the analysis results of the data collected nonetheless serve as a useful baseline for future trials of a similar nature. Still, compared to the present-day system of paper / digital maps, and voice-communications radios, it suffices to conclude that the availability of a datalink and a C2 collaborative planning tool are expected to enable the air-land C2 elements, planners, and warfighters to more effectively exploit information in the battlefield.

In conclusion, while this LOE has shown that our helicopter pilots can carry out their missions successfully and effectively under a model of Mission Command, we are not yet going to recommend a change in doctrine for the SAF. Rather, the lesson that we have drawn from this LOE is that the desired outcome of agility comes not from putting in place a set process or doctrine, but rather from putting in place networks and systems that would allow a well-conditioned team to adopt the mode of command and control most suited to the mission and situation at hand.

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