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Command and Control Experimentation using Distributed Simulation

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Abstract

A multi-national virtual battle experiment (VBE-E) was developed and run in Oct 2006 using the Combined Federated Battle Lab Network (CFBLnet) in order to conduct a rigourous distributed command and control experiment. The C2 scenario was a small coalition convoy escort operation facing a possible surface swarm attack. Each of the two naval frigates was represented by a core command team of four military officers supplemented by civilian interactors to represent upper deck sentries and UAV operators. The experiment was structured to have each nation run its frigate in the synthetic environment from its home nation. A generic C2 system was developed for the experiment and all command teams were trained prior to the experimental sessions. This paper concentrates on the infrastructure and procedures required to implement the experiment design, and it describes some of the technical and procedural lessons to be learned. Interoperability issues of working with multiple nations; both military and research organizations were highlighted. The nations involved spanned the globe so that issues of time (both technical latency and crew work hours) were significant.

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1.0 Introduction

The TTCP (The Technical Co-operation Program[1]) Maritime Systems Group (MAR) Technical Panel One (TP-1) on Maritime C2 and Information Management has been developing the concept of Virtual Battle Experiments since 2000 [1-4] to enable scientific investigation of its mandate. Virtual Battle experiments in this context are investigations that are conducted within a synthetic environment, which provide the subject (man or machine) with the inputs expected from a battle field environment.

The TP-1 distributed simulation infrastructure is based upon the Virtual Maritime Systems Architecture (VMSA)[9]. VMSA is an instantiation of the High Level Architecture (HLA) distributed simulation standard that is tailored for maritime command and control applications. Each national member of the panel contributes elements of the overall infrastructure in order to develop a larger capability.

Virtual Battle Experiment Echo (VBE-E) [5] is the latest in a series of TTCP and national experiments to use the infrastructure to investigate C2 issues and experimentation infrastructure. While the experiment had a number of objectives, this paper will concentrate on the aim to extend the VBE concept from single run discovery experimentation at one location; to multiple-run scientific exploration distributed between several locations. The capability of doing Human in the Loop (HIL) experimentation in a distributed manner is, from a coalition point of view, expected to help make the experimentation cost effective – thus enabling the participation of all coalition nations[2]. The expected benefit of this program is an enhanced capability to conduct Coalition Concept Development and Experimentation (CD&E) that is available to all coalition members. It should be noted that infrastructure development is not TP-1's primary mandate and the use of VBEs is only one tool for the conduct of coalition research.

The main objective of this paper is to examine the technical and procedural issues that the experimentation team encountered during VBE-E. Overall the experiment was a success and has added to the knowledge base that will enable the member nations to progress concepts for the use of UAVs. In addition, a large amount of knowledge in the collection of human factors information was obtained, and is reported in a companion paper at this conference [8].

2.0 Virtual Battle Experiment – Echo Experimental Plan

The combination of geo-political events and the practical application of sea power has forced coalition navies to re-examine their capabilities to operate in the more complex littoral constrained zones. Platform vulnerability and the need for platform protection is also important as opponents develop concepts of operation and weapon systems to counter coalition operations.

A significant class of threat is a swarm attack by small boats. In swarming tactics a large number of FIAC simultaneously attack a target, often from multiple directions and can overwhelm the defender. The small Fast Inshore Attack Craft (FIAC) are high speed, maneuverable, and often indistinguishable from pleasure craft or fishing boats. Since these

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[1] TTCP – The Technical Cooperation Program, a five country (Australia, Canada, New Zealand, United Kingdom and United States) agreement to carry out collaborative research in non-atomic defence applications.

[2] Distribution of the simulation elements should remove the requirement for travel and separation of military participants from their units.

threats are covert, the time and space constraints of the littoral environment on detection and classification of the enemy leaves little time to react and engage with an appropriate response.

In 2002 a multinational study group on Net-centric operations, TTCP Maritime Systems Group (MAR) - Action Group One (AG-1) used operations research techniques to examine force defence effectiveness for a small coalition force facing a surface swarm attack[6]. AG-1 recommended a number of C2 related "net-centric" applications that improved effectiveness. With TP-1's focus on Maritime Command and Control issues it made sense for TP-1 to take on the task of examining some of the C2 recommendations in more detail. Moving from the higher level OR modelling to more detailed HIL studies also fits well to the spiral development model espoused for Concept Development and Experimentation (CD&E) and the TTCP GUIDEx [7]. In particular two recommendations were picked for examination and hypothesis testing:

1. the use of Unmanned Aerial Vehicle (UAV) to extend sensor ranges, and
2. the capability for third party targeting of weapons to allow increased weapon availability

It was decided in April of 2005 that this project was also well fitted to extending the VBE synthetic environment across the internet. A team, led by Canada, was put together to develop the experimental plan and required infrastructure extensions. An experimental plan was developed over 2005 and active software development was conducted in 2006. Using the TP-1 infrastructure a synthetic environment would be designed to allow for multiple sets of runs so that statistical confidence could be built in the results. A pilot study of the experimental plan was conducted in August and the actual experiment was conducted over the two weeks of 2-14 October 2006.

2.1 Objectives

The primary objective of the experiment was to test, using HIL experimentation, the hypothesis that the addition of a small UAV or third party targeting would improve coalition convoy defence in constrained waters against swarm attacks with light weapons. Associated with this, was the objective to demonstrate the ability to use VBEs to conduct hypothesis testing experimentation in a cost effective manner, and using a distributed architecture. VBE-E also had secondary objectives to advance TP-1's capability to measure workload and situational awareness.

2.2 Scenario

The actual geographic area to be used in the experiment will be the Northumberland Strait, 46˚N 63˚W, between the Canadian provinces of Prince Edward Island, New Brunswick and Nova Scotia. Three dimensional (3D) terrain was generated to provide background for visual and electro-optic sensors on the UAV.

- The weather conditions will be sunny and clear, with no noticeable sea state.
- There will be navigational tracks for the ships to follow.
- There will be some neutral merchant traffic, fishing and pleasure craft.
    - There will be a number of situations in the scenario that feign the possibility of an attack and which may induce false alarms.

Maritime scenarios were developed to provide a wide range of maritime traffic. Figure 2 shows an example of the initial conditions for Scenario 6.

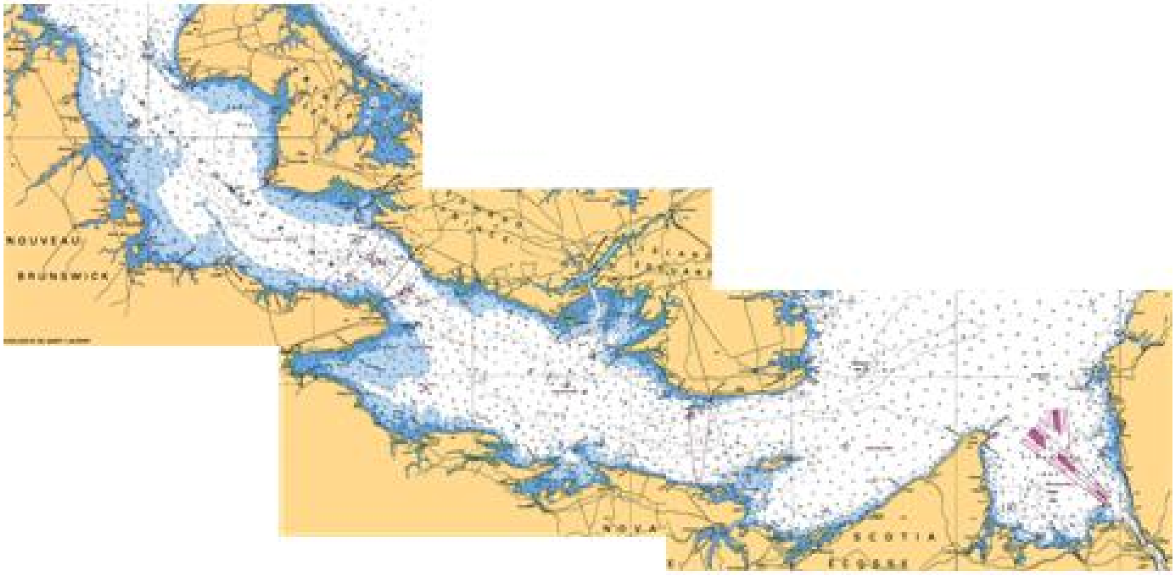

Figure 1: VBE-E Scenario Location – Nautical chart of Northumberland Strait

The scenario was that two nations existing on either side of the strait have had a decade of deteriorating relations caused by competition for access to the economic benefits from use of the strait. Several years of debilitating pseudo-war have reduced the countries to near anarchy and organized crime has moved in and taken control. The UN has been asked to assist the nations in resolving their disputes and regaining control of the strait. A small coalition has been given the task of re-establishing the rule of law. At the tactical level the officer in command (OTC) has been given the task of showing the coalition's determination by ensuring the safe passage of a small convoy of ships through the strait. Intelligence suggests that the organized crime elements will attempt to oppose this by attacking the convoy. However, it is assessed that they do not yet have access to heavy weapons or specialized vehicles. The coalition forces consist of two naval frigates with 77mm main guns, 50 cal machine guns, surface search radar and ESM, and possibly a small maritime UAV with optical sensors.

Rules of Engagement (ROE) are that hostile intent must be determined before deadly force can be applied. Principles of self-defence have been extended to cover the whole convoy, but individual frigates are constrained by national ROE where there is conflict. Authority is given for warning shots, running off suspects and deadly force in defence of the convoy. Declaration of hostile intent requires either attack, or evidence of intent (ignoring radio, verbal and shot warnings) coupled with evidence of capability (visual sighting of weapons).

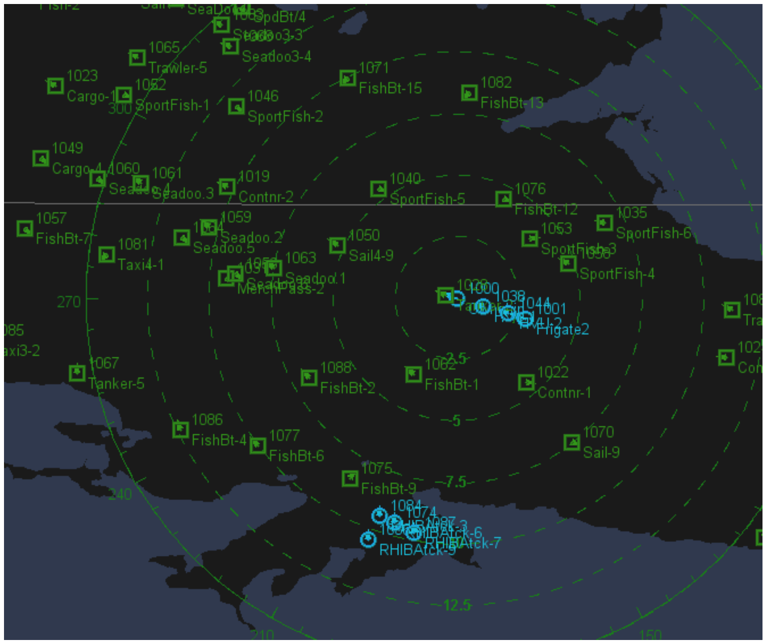

Figure 2: VBE-E Scenario 6 initial platform locations, showing the convoy location in mid-strait in blue, and the attackers in blue at the bottom.

In each scenario, the convoy started at watch turnover at a location in the strait with a mission to transit in a particular direction or to a particular destination. Attackers start somewhat dispersed and transit to a gathering point before launching a high speed attack from 1-2 directions. It is only after the high-speed attack has begun that attackers show indications of weapons.

2.3 Experimental Conditions and Methodology

The experimental methodology was to set-up a virtual frigate operations rooms with the four HIL command team positions in each nation. The operations rooms provided the command elements of a two frigate coalition convoy. Common, generic combat control system (CCS – based on Horizon), frigate weapons systems and frigate platform capabilities would be used to control for equipment differences. Each pair of command teams would face a swarm attack threat and have to protect the convoy. Attackers would be limited to short range weapons (<1000m range) but would have a speed advantage on the convoyed vessels (30 vice 20 knots).

The command team's performance in defending the convoy from a swarm attack formed the basis of the response variables. The command team consisted of a Commanding Officer (CO), Operations Room Officer (ORO), Force Protection Officer (FPO), and Surface Weapons Controller (SWC), or national equivalents

The treatments were variations on the frigate capability available to them; that is, a baseline capability, and the baseline plus a single small UAV:

Baseline: Frigate with radar, sentries, 50 cal machine gun, 76mm main gun.

UAV: Baseline + a small, max 100 knot UAV with a 64x optical sensor.

The UAV was representative of the small UAVs being proposed for naval operations. That is a 2-3 hour endurance, and maximum speed of 100 knots. The frigates were also given the ability to use tracks from the other ship to target their main gun systems. Since many navies are in the process of obtaining this capability, and there was a need to limit the number of treatments, this was not an independent treatment but part of the baseline frigate capability.

Participants were drawn from qualified naval personnel in each nation and underwent a common training program to provide familiarity with the equipment. National Human Ethics Review protocols were developed in each nation and applied to the experiment.

The experiment conditions were varied over the subject population (differing combinations of command teams) and swarm attack timing. In order to control for team learning a further variation in the overall background traffic and start location in the convoy transit were introduced. No single crew would see the same scenario for more than two runs (once for each treatment). Further, paired scenario runs were separated in time to reduce recognition between treatments.

Experimental runs were scheduled to make full use of the available time while keeping to normal working hours for crews in all countries where possible. Each run was scheduled to take between 40 and 120 minutes, with no attack taking place in the first 30 minutes of a run. Runs consisted of 15-20 minutes of briefing, a 30 minute watch handover and ramp up period, followed by up to 90 minutes of play during which an attack would take place. Following the run, two questionnaires were completed; one on workload and, one on situational awareness and feedback on the run. In total three hours were budgeted for each run, including pre- and post-run data collection, briefing and debriefing of participants.

Data Collection

A wide variety of data collection was planned in order to provide as much data redundancy as possible. A combination of automatic data-logging within the synthetic environment, observation records, video and audio data would be recorded for the analysis, including the calculation of the following measures of effectiveness:

- Response time - Time from initial detection to classification as hostile (or from attack initiation to classification)
- Response lag – Difference in time from when information used to classify as hostile available to actual classification.
- Open fire range (minimum range of attackers to target at time of first shot) for each ship.
- The number of leakers which is defined as the number of FIAC which make it to within attack range of the target. Attack range values will be based on AG-1 and TTCP MAR AG-5 values. This is the MOE used by AG-1 and will allow for direct comparisons with the MANA modelling in that study.
- Attack duration – time from start of attack to time last attacker is destroyed or gets to attack range.
- Damage to neutral vessels

A pilot study was used to examine the experimental methodology and infrastructure using non-military personnel a month prior to the experiment date and prior to full access to the classified network. The pilot study is a required element in the Canadian ethics protocol and provides the opportunity to assess the variability in results and determine deficiencies in methodology and analysis.

2.5 Infrastructure

2.5.1 Synthetic Environment

The VMSA HLA distributed synthetic environment developed for previous VBEs would be extended to provide the synthetic environment for VBE-E. This environment included radar, ESM, ship movement and a UAV. In addition, the Joint Semi-Automated Forces (JSAF) simulation had been obtained by Canada for experimentation support purposes and was assessed as being able to be bridged into the distributed simulation to provide the non-coalition platforms. Figure 3 shows the federation structure for the synthetic environment.

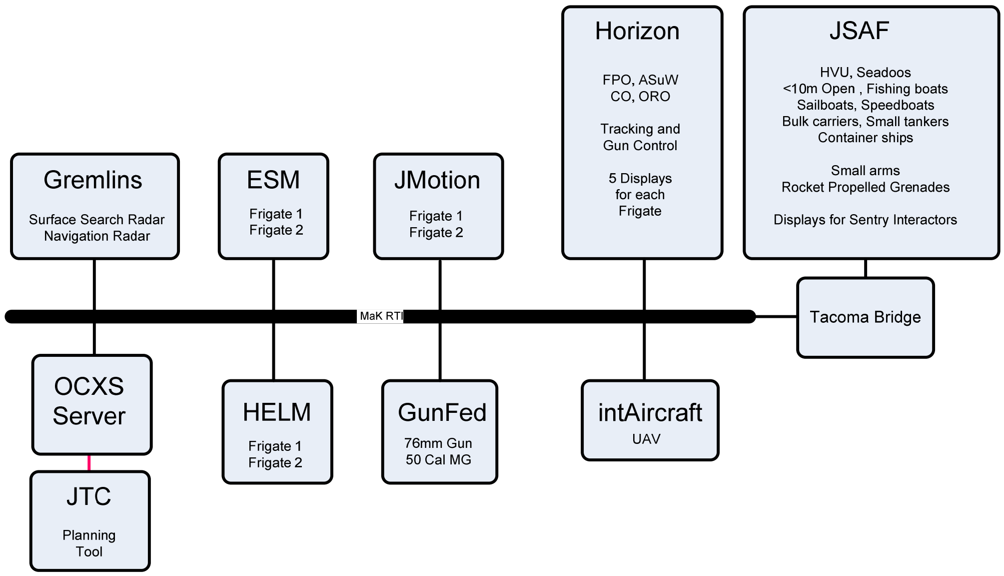

Figure 3: VBE-E Federation structure.

Additional development by the nations would add 3D representations of the background traffic and red forces, gun control for the frigates, collaborative planning tools, bridging software between VMSA and JSAF, data collection software, and a replay capability. The 3D representations were constructed to give a variety of types, colours and occupants. In addition, to enable the discovery of hostile capability using the UAV, versions of some of the 3D vessels had weapons added. Figures 3 and 4 show an example of armed and unarmed models. The armed models were activated when attacker affiliation in JSAF was changed to hostile at the start of an attack run. This affiliation change marked the earliest point that hostile intent could be legally determined.

Figure 4: Unarmed Cabin Cruiser

Figure 5: Armed Cabin Cruiser

Several federates required development or modification. The main capability lacking was the ability to fire guns since previous experimentation had used other weaponry, or non-HIL control. This new federate had to integrate with the CCS and with JSAF so that neutral and red forces would sustain damage. A number of the other infrastructure elements, such as the bridge federate, required updating of capabilities or integration to work with JSAF. In addition, the overall infrastructure was moved from the DMSO HLA run-time infrastructure (RTI) to the commercial MaK RTI in order to improve maintainability and simulation speed.

2.5.2 Combat Control System (CCS)

The CCS commonly used by TP-1 is based around a C2 test bed developed in Australia by DSTO and Innovation Sciences called Horizon [9]. Horizon provides the ability to simply configure and/or augment a common CCS workstation with experimental capabilities. In addition, individual Horizon instances can be linked together either through HLA or a socket based network. A common configuration of six Horizon instances was developed for each frigate operations room (Figure 6). The two frigates were then linked using simulated communications and HLA as shown in Figure 7.

Internally, the CO worked in conjunction with the ORO's display. The ORO had overall control of the picture, and using the ORO-Link instance had the ability to share tracks with the other frigate. The SWC had control of the radar picture and 76mm gun, while the FPO had control of six 50 cal machine guns and was the link to the Sentry interactors. Sentries were given a Horizon showing truth tracks and a set of instructions on the ranges that identification information could be given to the FPO.

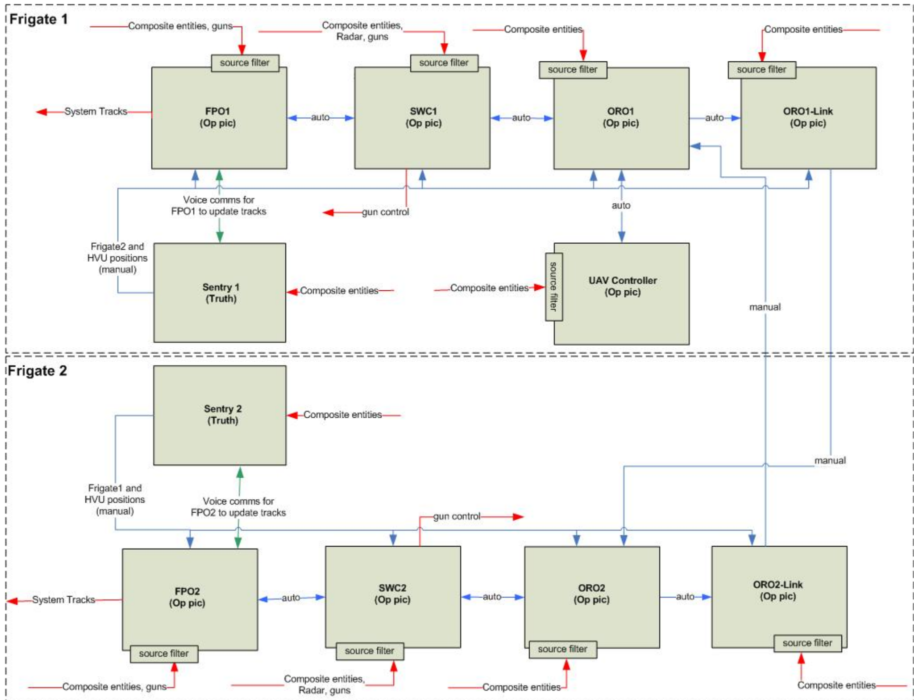

Figure 6: VBE-E Combat Control System (CCS) instantiation using Horizon C2 Testbed instances.

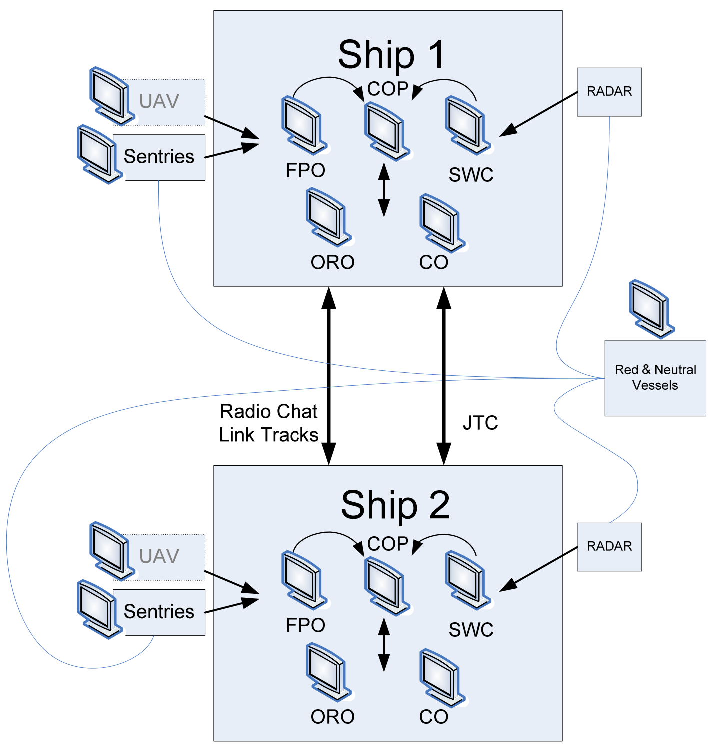

Figure 7: Human in the Loop Diagram – screens represent individual machines, blue lines show influence on sensors, black arrows show communication between machines. The UAV is only available during specific experimental runs and on a single platform at a time.

Communications were simulated using the commercial gaming program TeamSpeak. Teamspeak was configured to give three radio channels: Coalition tactical UHF, marine VHF and Excon/interactor. In addition, the COs were given a chat facility and access to an experimental collaborative planning tool.

2.5.3 Network

All nations are members of the Coalition Federated Battle Laboratory network (CFBLNet), a classified network for experimentation. Previously, TP-1 had conducted some limited experimentation on the CFBLnet to assess its ability to sustain distributed simulation. While, the results were mixed in that trial, data on the quality of service available was collected and it was felt that with some development the synthetic environment could be run on it. Risk reduction would be conducted using a Canadian built wide area network emulator (WANE) to test the synthetic environment with CFBLnet characteristics prior to deployment on the actual network. In testing on WANE, the experimental infrastructure ran easily at better than real-time with the expected latencies to Australia.

2.5.4 Data Collection

A specialized data logging federate was developed to log all distributed simulation data, while Horizon provides internal logging of tracks and interactions. A PDA based observer recording application developed in Australia was used for recording participant interaction data, while the UK developed electronic versions of the questionnaires and Canada provided an electronic workload questionnaire. All data except video was to be stored on an ftp server provided by the UK on the network.

2.6 Timeline and Project management

Application for network time was initiated in Jaunary 2006 and software development was planned to begin in early 2006. Integration was scheduled to take place in July, with a pilot study in August; followed by a final Project Team meeting. Training would take place in September with the experiment occurring in early October. Analysis would be conducted through the latter part of October to provide a QuickLook and full report finished in April 2007.

Software development and integration was led by Canada, who did the simulation integration and debugging. Following initial integration the pilot study in August was to be used to determine usability by the project team, collect data on variance of results and finalize experiment configuration. The software was released by Canada through an ftp site provided by the UK on the CFBLnet. Simulation control for runs was controlled by either Canada or Australia depending upon the time of day of the runs.

2.7 Analysis

Analysis of the data collected would be focussed on three principal tasks:

1. Reconstruction of the runs and calculation of the measures of effectiveness
2. Analysis of the human factors data to determine the usefulness of the variety of test instruments and procedures trialled
3. Evaluation of the technical infrastructure used for the experiment.

Data collected will initially be reviewed and analyzed for trends in performance measures. The data will then be categorized and analyzed in more depth for dependencies on scenario. A reconstruction tool that can utilize the simulation data-logs would be developed in parallel to the synthetic environment development.

3.0 Actual Experiment

With some slippage in integration and development, VBE-E followed the planned schedule and occurred on time. A synthetic environment which supported the experimentation requirements was developed and executed to obtain 15 runs, giving 7 sets of UAV/noUAV treatments using crews from Australia, Canada and the United Kingdom. Five of the runs were conducted over the CFBLnet between Canada and the United Kingdom, while the other ten were conducted at DSTO Pyrmont in Sydney Australia using crews from Canada and Australia. Analysis has taken place and the report was published on time. So it was a success, of sorts.

VBE-E showed we could do distributed simulation and that the concept of distributed VBEs has a good potential for future experimentation. However, it also showed that the match between network quality of service and the synthetic environment has not been optimized. Simulation performance was good enough between Canada and the UK to conduct runs, but was not good enough with the longer time latencies between Australia and either Canada or the UK. Further, the simulation itself, being a complex system of systems, showed instabilities when on the network or deployed to other sites that did not occur within the development lab.

3.1 Synthetic Environment Development

The synthetic environment development was behind from the start as the development team was involved with another national distributed simulation project that ran two months overtime. Since some elements (bridging software, JSAF) were common, this did not seem to be as bad as it turned out to be. The development of the bridge to JSAF and the gunnery controls were progressed as expected and included extensions to the VMSA federation object model to cover gun controls and munition detonations. In parallel with this, the Detailer data-logging federate was developed to record the simulation data from the HLA distributed simulation.

As might be expected the real work came in integrating the various elements together. While technically getting the various elements to talk to each other went fairly smoothly, integrating behaviour was more difficult. Since, a distributed simulation is, by definition, a system of systems, isolating problems was often difficult. For example, the gunnery federate calculated gun ballistics quite accurately, however, the JSAF simulation, where damage to red and neutral vessel damage is assessed, was on the other side of a bridge from the time-managed VMSA portions. So when shells that should have been hitting targets with absolute accuracy were not sinking vessels it took awhile to track down the problem, which was that with latency it could not be guaranteed that the ammunition splash point determined on one side would correspond accurately with the vessel positions on the other side. Further more, it was determined (after some investigation) that JSAF required a shell to hit within a ship width of the vessel centre of mass in order for there to be damage. This makes it much harder to hit small vessels than large; and with time latency discrepancies, almost impossible to hit small vessels. The solution adopted was to have the bridge to match the target to the non-time-managed JSAF positions and add an error; not elegant but effective. In another case the time lag in promoting tracks between individual CCS workstations was sufficient that track attribute changes could be made to cycle around the network of workstations. The developers of Horizon put in a great deal of time debugging – long distance from Australia.

Then there were hardware problems. At least one problem that took a week to track down and solve was fixed by replacing a hardware network switch in the lab. Evidence suggests that there was a progressive degradation in switch performance. The biggest problem with these delays was that the software team were also the scenario developers and system operators for the pilot test. In spite of these problems a system was put together in time for the pilot study in mid-August, but without having gotten the analysis software developed or having been able to complete full integration testing.

Following a week of in-house pilot testing that found numerous minor problems, the full project team met to review the infrastructure and experimentation methodology. With hindsight, the project team meeting should have been held before the pilot study as a number of fundamental changes to the operations room layout were made which required another round of configuration and testing. This work pushed the team past their deadlines for software distribution to the other nations, and used up time that had been budgeted for scenario development and training plan development. Thus, at the end of August the basic simulation infrastructure was in place, but the network was unavailable and training procedures and scenario development were still being prepared.

3.2 Participants

On the personnel side the issue of getting participants was a two edged sword. On one side it was difficult to get personnel identified and assigned; while on the other side once they were committed the experimentation team was committed to a particular time frame. It had been hoped that running the experiment in-country would ease the problems of finding qualified participants. Given the tempo of operations, in fact, overseas travel might actually have been an incentive to get crews, although getting travel funding would have been problematic. In several of the countries, crews were identified, committed and then lost to higher operational requirements. Of the crews used, the British and Canadian crews were supplemented with military liaison officers from the laboratories, while Australia was able to provide a complete crew for one week and a composite crew for the second. Both the UK and New Zealand were only able to identify crews for one of the two weeks.

Civilian participants were used for the Sentry and UAV operator positions to decrease the number of military personnel required to be sourced.

3.3 Network

On the network side, a low-bandwidth link was requested for May-Aug with a high bandwidth (3Mbs) link for Aug-Oct. The project was initially proposed in January, but the actual paper work was not finalized until late June, and accreditation was finally granted in mid-August. Network connectivity was not established between Canada and the UK until mid-September, partially due to the requirement to find enough available crypto gear. Thus, it was the week before training that the software engineers finally got a chance to test the software on the real network. Although, they had tested it on an emulator with the maximum expected latency and requested bandwidth, there was little time for integration and testing. Further, this was the first opportunity to work with the software that had been independently installed in the other countries. A partially working system was available for training between Canada and the UK by the planned training week. However, although the network came up in New Zealand at the same time, personnel limitations meant that they did not have the surge capacity to do the system install, and testing in the reduced time available, and they reluctantly had to withdraw from the experiment. It should be said that it took most of the available resources in the other nations to get their systems up and running. The point being that smaller coalition nations will often not have the resources to surge when systems arrive late.

3.4 Training

Training between Canada and the UK went fairly smoothly given that the training program was developed by the same personnel who were developing the scenarios and troubleshooting the software. A gradual build of capability was used, with initial training by individual nations, followed by joint procedural training, and then finally integrated operation of the system. Observer training was conducted in parallel, with the last training day being with the full system of participants and observers. Without NZ to pair with, Australia conducted training the following week using two labs at DSTO Pyrmont for their two teams. An Australian scientist travelled to Canada for the CA-UK training week in order to learn the system and provide continuity in the training program.

3.5 Experimentation

The first run of the actual experiment was between Canada and the UK on 2 October and was a complete success. The second run was Canada and Australia (Canada's evening, Australia's morning) and was a complete failure. Network tools showed up to 10% packet loss and the simulation was unable to make better than 40% of real-time rate. While the network technicians tried to figure out what might be wrong, the team continued to try to conduct runs. The second CA-UK run – using the same software as the first run - had numerous software failures and less than real-time rates. Over the rest of the week, despite many configuration and equipment changes, a good link to Australia from CA, or UK, could not be obtained. Since the UK crew was unavailable after the first week, the decision was made to take the Canadian crew to Australia, and try to get as many runs in as possible. Australia was picked instead of Canada because they had a second classified room with infrastructure that could be used. Table 2 gives the schedule of runs for week two in Australia.

Table 1: Schedule for Week 2

Run	Day	Country	Country	UAV or Base	Excon	Scenario	OTC
W2.1	Oct 11	CA	AS	Base	AS	5	AS
W2.2	Oct 11	CA	AS	UAV	AS	6	CA
W2.3	Oct 11	CA	AS	UAV	AS	4	AS
W2.4	Oct 12	CA	AS	Base	AS	7	CA
W2.5	Oct 12	CA	AS	UAV	AS	8	AS
W2.6	Oct 12	CA	AS	Base	AS	6	CA
W2.7	Oct 13	CA	AS	Base	AS	4	AS
W2.8	Oct 13	CA	AS	UAV	AS	5	AS
W2.9	Oct 13	CA	AS	UAV	AS	7	CA

W2.10	Oct 14	CA	AS	Base	AS	8	AS

In Australia, problems continued to plague the system, as the performance of the simulation seen in Canada could not be repeated. In spite of the problems, ten runs (5 run sets) were completed, although most of them have some type of data missing as the technical team tried to debug the system between runs and elements of the simulation were removed or modified.

3.6 Analysis

The result of the compressed development time, and long hours of system debugging meant that the development team was unable to get to the task of constructing reconstruction/analyzer software until after the experimental runs were completed. In fact, the small teams were completely burnt out by the long hours. An analysis workshop had been planned to coincide with the TP-1 annual meeting in early November – this was postponed until early December and then to February, when it became clear that the team needed more time to recover from the experiment and build analysis software. The human factors team had a separate analysis meeting in early December to analyse the workload and situational awareness data.

During November and December a purpose built reconstruction software that could read in both the simulation and Horizon data logs was constructed to assist in the calculation of measures of effectiveness. The Analyzer software allowed the replay of the scenarios and the calculation of distances and times. It also allowed the display of gun fire and munition detonation events so that detailed distance and time calculations could be made. Figure 7 shows the truth reconstruction of Scenario 6, whose initial positions were shown in Figure 2. The attackers can be seen moving from the south to a collection point and then forming into a two pronged attack on the convoy. The tracks only become hostile (and therefore identifiable as hostiles) after the attack is initiated north against the convoy.

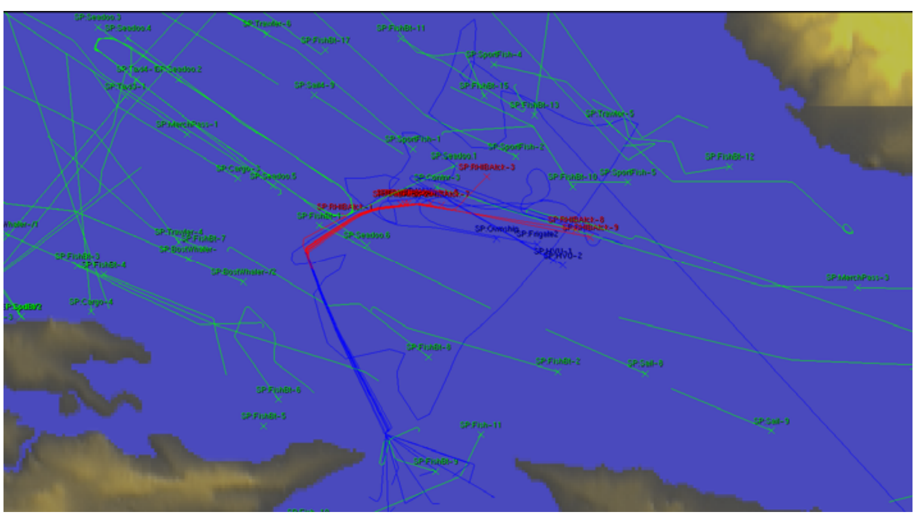

Figure 7: Truth reconstruction of Scenario 6 showing the track of the convoy and UAV, as well as the swarm attack from the south.

The reconstruction process required the use of both the Analyzer software and review of the video and audio recordings in order to determine events like when tracks were made hostile. While it was assumed that a track would be made hostile and then fired upon, due to the short time intervals in several cases tracks, were not declared hostile in the system until after they had been declared hostile by the CO and fired upon by the ship. It was also determined that many of the intended measures were compromised by actual procedures, and an additional measure was added to the analysis. The new measure, Hostile Range, was defined to be the range of an attacker at the time it was classified as hostile. This measure is neutral to the effects of weapon system modelling, type of threat, and order of engagement, but characterizes the distance/time available to a platform to handle the engagement. Longer Hostile Ranges are better since they provide more time to counter the threat. This is different from detection range as a key feature of asymmetric threats is that they are easily detected (they look normal) but difficult to classify.

4.0 Lessons Learned and Conclusions

4.1 Development

- Get the network up long enough before to do network integration + pilot + training before the experiment. For VBE-E about eight weeks should have been the minimum time between network availability and the experiment. Eight weeks gives a week for integration testing, pilot and training, and 2-3 weeks for fixing problems between integration testing and pilot study, and between the pilot study and training weeks.
- Distributed simulations for C2 research are complex systems. Expect emergent issues to arise that are difficult to track, and budget integration time accordingly.
- Integration testing with HIL should be done early in the process, followed by a full review by the experimentation team. Enough time needs to be left following this review to adjust the infrastructure before a pilot test with qualified participants. The pilot test should include a dry run of data analysis.
- Off the Shelf (Commercial – COTS or Government - GOTS) tools can be very powerful, but are often complex and include assumptions that may not be apparent. If the tool is new, or its features have not been used extensively, then extra time should be budgeted for integration testing and configuration.
- A full system description and review with qualified military operators should be conducted early on in the development cycle. The simulation needs to support all combat system functionality. Two examples in VBE-E were the lack of a “suspect” category in the CCS, and the inability to specify that a weapon firing was a “warning shot”. In VBE-E all shots were assumed by the developers to be active – fortunately the damage model in JSAF was erratic enough that most warning shots did not actually destroy the vessel. Further, warning shots need to be flagged to the attention of the white or red cell to allow appropriate response.
- A member of the development team needs to visit the other technical teams for system installation to ensure consistent system installation.
- Development and intstallation timelines have to take into account the limitations of personnel and resources of all of the players. In particular, smaller organizations may not have the capacity to surge support if phases of the experiment fall behind schedule.

Training

- Consistent training must be implemented for all participants, observers and operators.

- Participant training should provide a set of similar scenarios and expected response exercises to allow assessment of training levels.
- While the use of a generic CCS meant that all participants had to be trained on the equipment, it also meant that differences in equipment were removed from the variability in the experiment. However, a generic CCS may not be a good match to national C2 procedures and the resulting effects need to be taken into account during training.

Experimentation Procedures

- Participants will play the system, it is not enough to assume professionals will restrain themselves to actual capability. By nature warfighters are competitive and the synthetic environment must impose the real equipment limits. In VBE-E teams were discovered to be calling for unrealistic speeds for the ships and convoy, and entered waters (shallow sandy areas) that in real life they would not have gone, because there were no consequences in the simulation.
- In scenario design there is a need to think littoral. In VBE-E only maritime threats were considered, and therefore the OTC felt free to run the convoy close to shore. EXCON scrambled to introduce shoreline activity, but the scenario did not include any land based attackers so the response was limited.
- Technical support and EXCON must be different. If there are technical problems it is too easy for EXCON to get wrapped up in the technical details, and therefore to loose situational awareness of the overall experiment.
- The use of interactors to replace human elements of the system requires detailed instructions and training in order for them to provide the correct stimuli. In VBE-E, a single interactor was used to replace six sentries, and was given a 2D position plot showing truth positions and descriptions. The sentry interactors were given a set of rules for when to provide different levels of data on tracked objects. However, there were cases where the interactors provided better information than should have been available, and others where they could not respond properly to participant requests. It is clear that the position plots were not good enough, either 3D displays that simulate the use of binoculars and environmental conditions or much more detailed instructions are required.
- There needs to be Physical separation of EXCON, white/red players from the participants. There should also be local technical/EXCON representatives, however, the point of much experimentation is to stress the participants with less than full information. The participants need to be discouraged from trying to obtain more information than would be available in reality. On several occasions participants became frustrated with simulation performance and attempted to get the EXCON to provide more information, or to query EXCON on if the system were working directly. This was discouraged, but if EXCON had not been easily accessible it might not have been attempted at all.
- Good briefing materials on the scenario and the objectives of the experiment are required for each simulation run, both to ensure consistency and to mitigate any decline in motivation.
- HIL imposes deadlines once scarce resources are committed – hard to change timescales for a single organization, it is much harder when there are several.

Analysis

- Get analysis software built early so that it is available to test on pilot study data.
- The more types and kinds of data that can be recorded the better. Multiple recordings of the same data will allow data checking. The use of video and audio recordings is critical to understanding the complex environment of a command team.

5.0 Conclusions

Distributed rigourous experimentation is feasible, and with the correct development and preparation, cost effective.

With current technology, network quality of service is critical. Bandwidth and simple unloaded network measures are insufficient to specify the required quality of service.

Conducting coalition C2 research requires a recognition of the capabilities that each member nation can bring to the table, in particular that commitment to a project by a small nation can have much higher risk than for a nation with more resources.

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