REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
JULY 2009

2. REPORT TYPE
Conference Paper Postprint

3. DATES COVERED *(From - To)*
April 2008 – April 2009

4. TITLE AND SUBTITLE
A COALITION APPROACH TO HIGHER-LEVEL FUSION

5a. CONTRACT NUMBER
In House

5b. GRANT NUMBER
N/A

5c. PROGRAM ELEMENT NUMBER
N/A

6. AUTHOR(S)
Dale Lambert and Steven Wark (DSTO), Eloi Bosse and Luc Pigeon (DRDC), Clinton Blackman (DSTL), and Michael Hinman (AFRL)

5d. PROJECT NUMBER
459E

5e. TASK NUMBER
TT

5f. WORK UNIT NUMBER
P1

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

AFRL/RIEA
525 Brooks Road
Rome NY 13441-4505

8. PERFORMING ORGANIZATION REPORT NUMBER

N/A

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

AFRL/RIEA
525 Brooks Road
Rome NY 13441-4505

10. SPONSOR/MONITOR'S ACRONYM(S)
N/A

11. SPONSORING/MONITORING AGENCY REPORT NUMBER
AFRL-RI-RS-TP-2009-28

12. DISTRIBUTION AVAILABILITY STATEMENT
Approved for public release; distribution unlimited. PA# 88ABW-2009-1581 Date Cleared: 17-April-2009

13. SUPPLEMENTARY NOTES
This work has been presented at the 12th International Conference on Information Fusion (Fusion 2009) on 6-9-July-2009 Seattle, Washington. One or more of the authors is a U.S. Government employee working within the scope of their Government job; therefore, the U.S. Government is joint owner of the work and has the right to copy, distribute, and use the work. All other rights are reserved by the copyright owner.

14. ABSTRACT
This paper outlines a collaborative program of work in higher-level fusion being conducted between Australia, Canada, the United States, and the United Kingdom under the auspices of a TTCP panel on information Fusion. The paper shows how work from the four nations has been integrated through a common scenario, which the panel proposes to subsequently offer as a benchmarking scenario for the higher-level fusion community.

15. SUBJECT TERMS
TTCP, Information Fusion, Higher Level Fusion, Scenario development.

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Michael Hinman
U	U	U	UU	15	19b. TELEPHONE NUMBER (*Include area code*) N/A

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

A Coalition Approach to Higher-Level Fusion

Dale Lambert and Steven Wark
Command Control Communications and Intelligence Division
Defence Science and Technology Organisation
Edinburgh SA, Australia
{firstname.lastname}@dsto.defence.gov.au

Éloi Bossé and Luc Pigeon
Decision Support Systems Section
Defence Research and Development Canada
Val-Bélair, QC, Canada
{firstname.lastname}@drdc-rddc.gc.ca

Clinton Blackman
Defence Science and Technology Laboratory
Portsdown West
Fareham, Hants, UK.
cpblackman@dstl.gov.uk

Michael Hinman
Air Force Research Laboratory
525 Brooks Road
Rome, NY, U.S.A.
michael.hinman@rl.af.mil

Abstract - *The panel session presents collaborative work undertaken between Australia, Canada, the United Kingdom, and the United States on higher-level information fusion through The Technical Cooperation Program panel on Information Fusion. The session outlines developments that have been undertaken by the different nations and features a demonstration of different nation's products running collectively on the Coalition Distributed Information Fusion Testbed. The context for interaction is a scenario which the panel wishes to make available as a benchmarking scenario to the fusion community.*

Keywords: Higher-Level Fusion, Situation Assessment, Impact Assessment, Situation Awareness, Situation Analysis.

1 Introduction

This paper is concerned with the theory and practical implementation of higher-level fusion systems. It relates to a collaborative program of work in higher-level fusion that has been conducted between Australia, Canada, the United States and the United Kingdom through The Technical Cooperation Program (TTCP) panel on Information Fusion. The paper presents contributions from the four nations, showing how the work has been integrated through a common scenario, which the panel proposes to subsequently offer as a benchmarking scenario to the higher-level fusion community. The paper outlines developments that have been undertaken and the panel session associated with the paper features a demonstration of different nation's products running on the Coalition Distributed Information Fusion Testbed (CDIFT).

1.1 Vision

The remit of the TTCP panel on Information Fusion is to "…promote collaborative research and experimentation between the member nations in the area of Information Fusion …". The panel has embraced a broader vision, however. There is currently a tendency for data fusion proponents to belong to either a lower-level fusion or higher-level fusion camp, with the higher-level fusion camp operating more as an aggregation than as a community. The demand for data fusion at all levels, meanwhile, increases at a considerable pace as the effects of the Information Age propagate. In response the TTCP panel on Information Fusion is seeking to open up some its work and export its strong sense of community.

1.2 Content

The TTCP panel on Information Fusion has established a sense of community by collaborating on both theoretical and practical pursuits. The publication of a book by the panel ([1]) reflects the theoretical collaboration. This paper reports on practical collaboration.

Two ingredients have been essential for practical collaboration. The first has been the development of a common scenario as a context for collaboration. This allows participants to map their problems and solutions into a common environment. The second has been the construction of the Coalition Distributed Information Fusion Testbed (CDIFT). This allows products from the contributing nations to be exercised concurrently. Section 2 outlines the common scenario while section 3 presents the CDIFT architecture.

The remainder of the paper highlights some of the contributions from the different nations. Section 4 summarises Canadian scenario platforms, sensor models, trackers and early higher-level fusion capabilities. In section 5, aspects of the US Air Force Research Laboratory Fusion2^{+} product are presented. This is followed in section 6 by an overview of a United Kingdom clustering approach. Section 7 offers some remarks about the Australian higher-level fusion implementations, followed by the Australian higher-level fusion display technology in section 8. The subsequent two sections highlight vignettes in urban operations and coalition search and rescue respectively that are being developed for inclusion into the scenario.

2 Scenario

This section presents a very short description of a vignette ([2]) designed to stimulate and test high-level information fusion concepts and algorithms being studied by our TTCP panel. We created a scenario (context) called Atlantis in which vignettes can be developed to represent various defence and security problems (e.g. military strikes, combat search and rescue (CSAR), urban operations, cyber security, harbour security, *et cetera*.

Atlantis is a fictitious continent located in the North Atlantic Ocean, between Europe and Greenland. For the purpose of this scenario, the land areas of Iceland, Ireland and UK, Shetland excepted, do not exist. The shape of the continent looks like the USCON rotated by 90º with one third of its size. As shown in Figure 1, Atlantis is composed of six countries: Blueland, Orangeland, Redland, Brownland, Whiteland and Greyland. The historical background to the crisis is summarized in [2]. Briefly, in the nineteen century, most of Atlantis, Greyland excluded, formed the Radobecan Empire until the end of World War I when was divided into the five current countries. The change of the borders in addition to the different social, political and economic conditions have brought disagreements between the countries.

Figure 1: Location of the Atlantis countries.

One of the vignettes that we have developed so far is centred on a 2-ship convoy being simultaneously attacked by submarine and aircraft off the Atlantis west coast. The two surprised attacks occur while other activities are taking place in order to complicate the assessment of the situation. Those activities include commercial air traffic, maritime traffic, observation of whale migration, and other military operations such as air surveillance patrolling and missile deployment. Moreover, one of the opponent countries has planned to take control of the Celtic Straits on that day. This vignette called 'Military Strikes in Atlantis' describes specific military activities within an evolving context where various crises happened between the countries as illustrated in Figure 2.

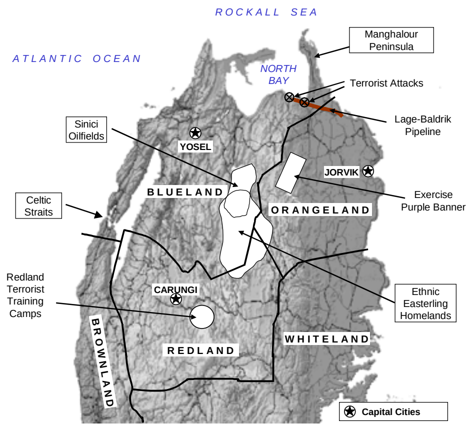

Figure 2: Location of the main conflicts prior to the current crisis.

The current crisis advanced when two mysterious explosions occurred in the Manghalour Peninsula. The first explosion hit one oil storage tank in Lage and the second one destroyed a section of the Lage-Baldrik pipeline. Orangeland widely argued that Blueland could no longer protect the oil reserves that are crucial to them from terrorist attacks. A week later, Orangeland forces invaded the Manghalour Peninsula, taking control of its airspace and moving forward surface to air missiles (SAMs). They promptly neutralized Blueland's air defence systems around the North Bay and took control of the Bay's entrance, confining several of Blueland's vessels of war, especially Fast Patrol Boat (FPBs) and Mine Counter Measure (MCM) vessels, near Breivik.

The UN Security Council (UNSC) progressively issued a set of resolutions to solve the crisis in northern Atlantis. The first resolution orders an immediate cease-fire and the withdrawal of Orangeland forces from Blueland. Further to the refusal of Orangeland to comply with that resolution, a second resolution was approved requesting all states to prevent any trade with Orangeland. The UN Security Council announced a third resolution imposing an embargo on Orangeland and requested the Alliance Council for military assistance to restore international peace and security in northern Atlantis. Two North America countries decided to participate by sending a task group to enforce that resolution. The task group, composed of 1 x Wasp class LHD, 1 x Burke class DDG, 1 x Iroquois class DDG and 2 x Halifax class FFG, have left their home base toward the North Atlantic Ocean and Rockall Sea.

The vignette is composed of various actions or activities occurring in the same time frame. Those components include the following.

Redland warships. Description of the operations carried out by the Redland Navy in support of the planned air attack of the Celtic Straits. Those operations include the dispatching of vessels in the Atlantic Ocean off the Celtic Straits, the boarding of merchant ships going to Blueland seaports in the Celtic Sea, and the escort of merchant ships from Redland seaports through the Celtic Straits.

Alliance Convoy. Description of the convoy composed of the cargo and Alliance Task Group leaving North America in destination to Atlantis.

Commercial Air corridors. Description of the air corridors used by commercial airplanes for the transoceanic flights between Europe and North America and the domestic flights in the Atlantis continent.

Blueland Ground-Based Radars. Description of the radar network used by Blueland Air Force for air surveillance and air traffic control.

Maritime Routes. Description of the commercial maritime routes usually taken by the merchant ships going to or coming from the Celtic Straits.

Whale Migration. Description of the platforms watching the humpback whales swimming off the Atlantis western coast towards the North Atlantic Ocean.

Missiles Deployment. Description of the missiles previously deployed by Redland in support of the air attack of the Celtic Straits.

Redland Airborne Surveillance. Description of the air platform used by Redland to detect and track operations carried out beyond its border.

Submarine Attack. Description of the attack of the convoy by an Orangeland submarine.

Air Attack of the Convoy. Description of the attack of the convoy by 2 Redland fighters.

Air Attack of the Celtic Straits. Description of the fighters sent by Blueland to counter-attack the Redland fighters and the attack performed by Redland to take control of the Celtic Straits. This second attack involves air, navy and ground platforms.

3 CDIFT

The Coalition Distributed Information Fusion Testbed (CDIFT) is an initiative of the TTCP panel to establish a distributed, heterogeneous coalition environment to support development and evaluation of information fusion technologies and applications.

The CDIFT incorporates a synchronous simulation layer using HLA to support ground truth and sensor modeling, and an asynchronous notional "Joint Task Force Information Grid" (JTFIG) to represent real-time access to coalition information sources and sensor feeds. The US Joint Battlespace Infosphere (JBI) is used as the primary medium for information exchange between coalition systems via a publish/subscribe model. Other technologies are also exploited, such as web services, and the Australian open-source Avis[1] architecture as an agent messaging layer. Applications access these layers as their information requirements dictate.

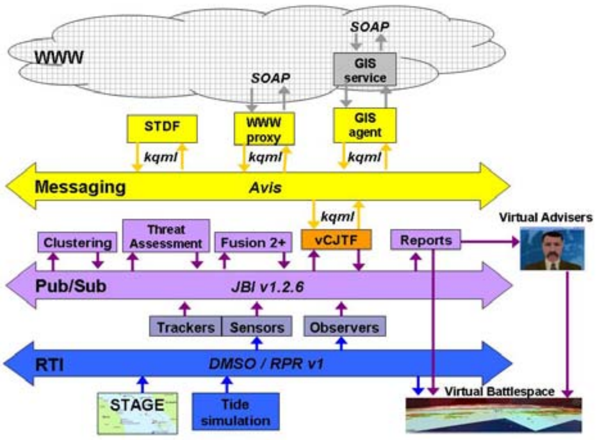

Figure 3: Architecture employed in the Coalition Distributed Information Fusion Testbed (CDIFT) provides a distributed, heterogenous coalition environment.

The functional components of the CDIFT follow.

1. Ground-truth generation is done using STAGE, which can inject ground-truth into the scenario in real-time, or be saved as data files for later playback.
2. Sensor modeling and tracking provides sensor and track reports that are published onto the JTFIG and available to any application that subscribes to these reports. Both 'cookie-cutter' and realistic high-fidelity sensor and tracker models are available on the CDIFT.
3. Information fusion applications and services subscribe to the sensor and tracker reports, and publish complete and/or partial information fusion products back on the JTFIG so as to be available to other applications.
4. Point-to-point communication between applications, subcomponents, or agents when processing information utilizes the agent messaging layer. This provides a level of abstraction that allows brokers to locate agents with the required capabilities, and multiple agents to negotiate an appropriate solution as the system complexity increases. The CDIFT is exposed as a web service using a web proxy. Agents register their capabilities with the web proxy, which then tasks them to satisfy web service requests.
5. User interfaces are provided by individual applications, and also by report subscriber services on the JTFIG. These can be deployed at whatever sites they are needed, and configured to only subscribe to

[1] avis.sourceforge.net

reports that are of interest to the particular site, role, or context. The way the information is presented to the users is also configurable to support different roles, contexts, and user preferences.

4 Platforms, Sensor Models, Trackers

The numerous agents (sensors, platforms, weapons, organisations, *et cetera*) of the vignette components listed in section 2 (Redland warships, Alliance Convoy Commercial Air corridors, Blueland Ground-Based Radars, Maritime Routes, Whale Migration, Missiles Deployment Redland, Airborne Surveillance, Submarine Attack, Air Attack of the Convoy, Air Attack of the Celtic Straits) are exercised through high-level information fusion applications on the CDIFT infrastructure of section 3, to help tell a story about what is going on in Atlantis.

Detailed simulations are being used to represent sensors (e.g. radars) and platforms. We attempt to simulate level 1 data fusion object assessments (tracks and id) since the object of our investigations is high-level information fusion. Below are short excerpts of the way each component of the vignette is being simulated. All details are described in [2]. For the purpose of illustration only, a couple of examples are outlined here.

4.1 Redland Warships

On their way to carry out naval exercises in the Atlantic Ocean, Redland vessels of war — 1 x FFG (Kotor class) and 2 x PCF (Rafael class: ex-Yugoslavia Koncar class) — have reported detecting submarine activities and found moored mines off the Celtic Straits. Redland claimed that the straits were no longer safe for the transit of merchant ships because of the likely presence of mines or submarines, and blamed Blueland for its conflict with Orangeland as being the main cause of the hazard in the straits. For that reason, Redland sent 2 x MCM (Birt class: ex-Yugoslavia Klanac class) and 1 x SSK (Elwood class: ex-NL Walrus class) to search for mines and submarines.

4.2 Convoy

A cargo ship carrying ammunition has just left a North America seaport in the direction of Bercelport (Celtic Sea) in Blueland, while the task group is going to the Rockall Sea (north of Atlantis). To protect the cargo from being boarded by Redland vessels, Blueland has requested that the task group escort her until they meet a Blueland Navy ship (1 x Descubierta class FFG) off the Celtic Straits. The frigate has deployed her towed array sonar and her CH-124 (Sea King Helicopter) ready to detect and hunt submarines. The frigate sails at 15 knots, 1 NM. ahead of the cargo. The helicopter is equipped with ping sonar and 2 x Mk-32 torpedoes.

4.3 Commercial Air Corridors

Two types of air routes are considered in this vignette: the North Atlantic air routes used for commercial flights between North America and Europe, and the Continental Atlantis air routes for air service between Atlantis airports. To make connections between European and North American eastern cities, airplanes have to fly over the northern Atlantic Ocean, and consequently the North Sea and the Atlantis continent, whereas European and North American western cities are usually linked through the Arctic. Figure 4 shows typical air routes used by airplanes to cross the northern Atlantic Ocean.

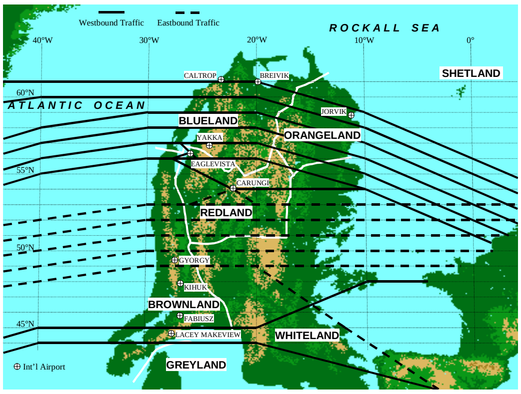

Figure 4: Typical routes of the North Atlantic Airspace.

4.4 Blueland Ground-Based Radars

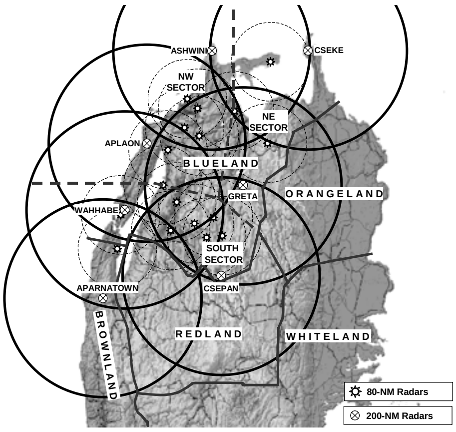

Figure 5: Location and coverage of the Blueland long-range and short-range radars.

Blueland airspace is divided into three Air Defence Sectors (North-East, North-West and South) as per Figure 5. The Operations Centre of each sector controls all flying activities (military, commercial and civilian) in the sector. The South Sector, which is in charge of the Celtic Straits area, is bounded to the south by the Brownland and Redland borders, to the west by the Atlantic Ocean, and to the north by the following segment points: 58º30'N 27º00'W, 58º30'N 25º00'W, 58º00'N 21º00'W, and the junction of the borders with Redland and Orangeland

(57º00'N 18º00'W). The Operation Centre of the South Sector is located at Nellis air force base (AFB) (57º06'N 22º22'W).

4.5 Events and ORBAT

A similar description applies for other components of the vignette ([2]). The exact time sequence of all events is in the simulation environment of CDIFT. In addition, each specific entity, such as a frigate, is simulated according to order of battle (ORBAT) information like that featured in the figure below.

FFG Halifax	**Sensors:** -Air search radar: SPS-49 (C/D-band; 457 km/250 NM; h:~65') -Air/surface search radar: Sea Giraffe (G/H-band; 100 km/55 NM; h:~85') -Fire control radar: 2 x STIR 1.8 (I/K-band; 66 km/ 36 NM for 1 m^2 target) -Navigation radar: I-band. -Hull-mounted sonar: SQS-510 (active search and attack; medium frequency.) -Towed array sonar: SQR-501 **Weapons:** -SSM: 8 x Harpoon (active radar homing; 130 km/70 NM at 0.9 M) -SAM: 16 x Sea Sparrow (semi-active radar homing; 14.6 km/8 NM at 2.5 M) -Gun: 1 x Bofors 57 mm (220 rds/min; 17 km/9 NM; weight of shell 2.4 kg) -Gun: 1 x 20 mm Phalanx (anti-missile; 3,000 rds/min; 1.5 km) -Gun: 8 x 12.7 mm Machineguns. -Torpedo: 4 x Mk 32 (24 x Mk 46 Mod 5; anti-sub; active/passive homing; 11 km/5.9 NM; 40 kt) **Countermeasures:** -Decoys: P8 chaff, P6 IR flares, Nixie SLQ-25 towed acoustic decoy. -ESM: Canews SLQ-501 (radar warning/intercept; 0.5-18 GHz) -ECM: Ramses SLQ-503 (jammer). **Aircrafts:** -Helicopters: 1 x Sea King (CH-124A ASW or CH-124B Heltas) (125 knots; 330 NM; Mk-32 torpedoes)

Figure 6: Sample from the Scenario ORBAT

5 Fusion 2+

The US Air Force Research Laboratory (AFRL) contribution to the CDIFT Testbed is the Joint Battlespace Infosphere (JBI) that is being utilized as the publish/subscribe environment by the other nations; along with the Fusion 2+ Testbed which will provide software tools for processing the text reports and analyzing them to determine the current situation. The Fusion 2+ testbed has been developed to support information fusion research and development. As first discussed in [3] and [4], the Fusion 2+ testbed is comprised of the following components:

1. Data collection
2. Document Parsing
3. Model Analysis

Initially, the analyst will specify a region of interest, and identify specific items of interest, which will be used develop (or modify) models. These models will then be used to drive the data collection.

The Data collection is performed via an AFRL developed meta-search engine that can simultaneously query and retrieve documents from multiple sources. These documents are then distributed for parsing.

Natural Language Extractors are utilized to parse free text messages and/or documents. Formatted messages, such as Tactical Reports (TACREPs), are processed by the Generic Intelligence Processor (GIP) ([5]).

Model Analysis tools then utilize the evidence provided to ascertain if any segment of a model is unfolding. The model analysis tool leverages graph theory, and searches the input graph (which is generated based on the evidence) for any subset of the target graphs (which are developed *a priori* by the analyst). Graph matches which exceed a specified threshold, are provided as potential alerts to the analyst.

The Fusion 2+ testbed, as envisioned for use in CDIFT, will require two modifications. First is the development of synthetic "open-source" documents based on the North Atlantis scenario vignette that will be used as the inputs to the Fusion 2+ software. These documents will either be in the form of TACREPs, or news reports. The other modification entails the development of new models for the Model Analysis tool. Once again, these models are to be specified by the analyst based on their experience with the area of interest. Both of these modifications are a work in progress.

6 Indicators of Collective Behaviour

The UK's Indicators of Collective Behaviour (ICB) algorithm exemplifies the potential that CDIFT offers as an environment for evaluating fusion algorithms. ICB was in fact not designed to be an operational tool, but rather as a training aid for future commanders to reveal the sorts of future capability that would be enabled by fusion. For this role, the ICB algorithm was developed for Dstl's Wargame Infrastructure and Simulation Environment (WISE) facility which is a formation level, land-based wargame used as an operational analysis model ([6]).

WISE can operate both as a wargame in which military players command simulated forces interacting in a simulated environment and as a simulation which operates without any human interaction. In a typical wargame, WISE might portray a complex warfighting environment with hundreds of manoeuvring entities under the control of "Red" and "Blue" commanders, each of whom responds to his perception of the situation which in turn is generated by the (simulated) ISTAR entities under his control. In general, each commander's view of the battlefield is both imprecise (because there is a stochastic element in WISE's sensor models) and incomplete (because of terrain, weather and sensor range effects). But the application ICB offsets some of these effects, leading to improved situational awareness and (at least in principle) measurably improved military outcome.

6.1 ICB Algorithm

The proposition underlying the ICB algorithm is that manoeuvring entities which are close together and/or moving at similar speeds and/or moving in similar directions are likely to be acting collectively and as such, might be posing a threat to a headquarters (HQ) or other deployed asset upon which they appear to be advancing. The algorithm has been fully described in [7], and it has three elements:

- Identification of candidate clusters;
- Assessing confidence; and
- Inferring intent.

6.2 Identifying Candidate Clusters

Assuming a total of N battlespace entities have been detected and tracked (either in the CDIFT or in the WISE wargame) and that their positions, speeds and headings are known (possibly with errors), a fully-connected bi-directional weighted graph of these entities may then be drawn up in which the edge weights (EW_{ij}) represent dimensionless assessments of separation, speed and heading:

$$EW_{i,j} = \left(\alpha \times \frac{d_{i,j}}{\max\limits_{i \neq j \in N}\{d_{i,j}\}}\right) + \left(\beta \times \frac{|\Delta s_{i,j}|}{\max\limits_{i \neq j \in N}\{\Delta s_{i,j}\}}\right) + \left(\gamma \times \frac{|\Delta h_{i,j}|}{\max\limits_{i \neq j \in N}\{\Delta h_{i,j}\}}\right)$$

where d_{ij} is the distance between entities i and j, Δs_{ij} and Δh_{ij} are differences in their speed and heading and α,β and γ are constants which can be determined dynamically at run time to give greater or lesser emphasis to separation, speed and heading criteria. Once the graph has been assembled, the Minimum Spanning Tree (MST) is calculated using Dijkstra's method and this is subsequently broken down into "forests" using a Gaussian Parzen Window estimator to identify edges which should be cut. The result is a set of candidate clusters (Figure 7).

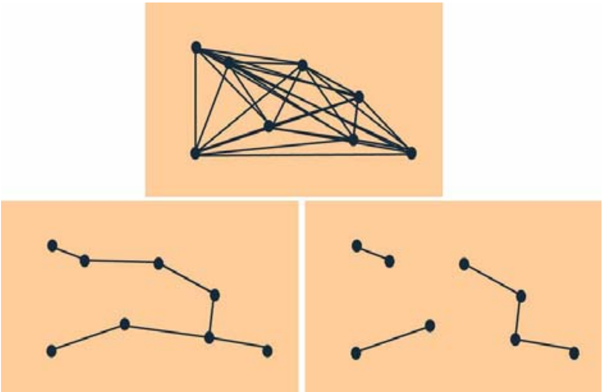

Figure 7: Example of an 8 node graph showing the Minimum Spanning Tree and subsequent allocation into candidate clusters.

6.3 Assessing Confidence

Once candidate clusters have been identified they can be monitored and in an operational system an analysis of cluster parameters over time would probably be the best way to assign measures of confidence in the coherence of each cluster. For WISE and CDIFT a simpler approach has been adopted, based on the (instantaneous) similarity of speed and heading between group members. The basic idea here is that a candidate group whose members display a "small" standard deviation in speed or heading is more likely to be genuine than one with a "large" standard deviation. Normalising by range, and taking due care to avoid numerical artefacts associated with the apparent discontinuity between 0°and 360° in heading gives a measure $Confidence_C$ defined as follows:

$$Confidence_C = \left(\frac{\beta \times \sigma(s_{i,j})}{\max\{s_{i,j}\} - \min\{s_{i,j}\}} + \frac{\gamma \times \sigma(h_{i,j})}{\max\{h_{i,j}\} - \min\{h_{i,j}\}}\right)^{-1}$$

Different confidence values may be used by commanders in deciding the priority order in which apparent threats will be addressed.

6.4 Inferring Intent

The point of CDIFT is that a variety of different information sources, including kinematic criteria and natural language reports, may be fused in order to infer intent. Within the ICB algorithm an initial indicator of intent is provided by a simple analysis of the overall direction that a group is taking in relation to known targets (in this case the locations of important Blue entities, such as HQs). A pragmatic approach for this has been developed that is quick and easy to compute, based on the angular difference in bearing, θ, between a target and the mean heading of a group. This is called a "Target Commitment Function", τ(θ), and it is defined as

$$\tau(\theta)=0.5[1+\cos^{2n+1}(\theta)]$$

where θ is the difference in heading between that of designated target and the mean heading of the cluster and n is a free parameter, designed to give an appropriately shaped functional form (in initial work n was set to a value of 10).

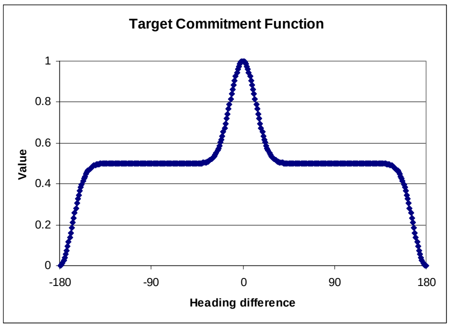

Figure 8: Target Commitment function for n=10.

The advantage of this formulation is that τ lies between 0 and 1 and it is essentially tri-valued, with τ=1 indicating a cluster that is moving towards a target, τ=0 one that is moving away and τ=0.5 representing the undecided case (Fig 2). Exact values of τ may be used to help Blue commanders prioritise between different threats and make appropriate force allocations.

6.5 CDIFT application

In the North Atlantis "Military Strikes" scenario there are a number of entities that are genuinely moving together such as the F16 fighters and shipping convoy. These are readily identified by ICB, giving confidence that more complex behaviours expected in other CDIFT vignettes will also be correctly discovered and at the same time providing a diverse set of situations within which the ICB confidence and intent indicators and other parameters may be studied.

The successful transition from a land-based training aid to a marine-based "operational" tool has demonstrated the flexibility of the CDIFT testbed as well as providing valuable opportunities for refining the ICB algorithm.

7 STDF Model

The Australian State Transition Data Fusion (STDF) Model ([8],[9],[10]) was developed as a unifying model across the JDL levels of fusion ([11]).

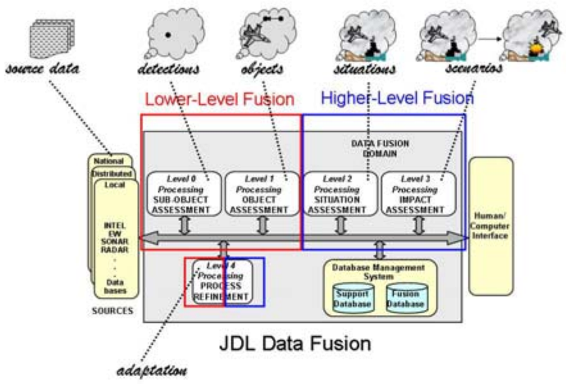

Figure 9: The JDL Model of Data Fusion

The STDF Model is based on two premises.

1. At each level of fusion the world can be assessed in terms of states and transitions between those states. For example, level 1 states are *state vectors*; level 2 states are *states of affairs*; level 3 states are *scenario states*; with *objects*, *situations* and *scenarios* being the sets of respective transited states over time.
2. At each level of fusion, the fusion process adheres to the *same pattern of behaviour* but the *nature of the content changes*. Figure 10 illustrates the common pattern of behaviour. For example, registration is *coordinate registration* at level 1; *semantic registration* at level 2; and *situation assessment* at level 3.

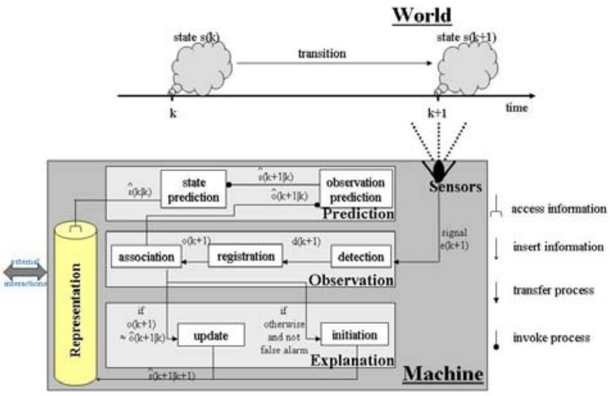

Figure 10: STDF Model.

This section of the paper focuses on implementation of the STDF model for higher-level fusion in the context of the North Atlantis scenario.

7.1 State Representation

Figure 11 presents the STDF Model for level 2 situation assessments.

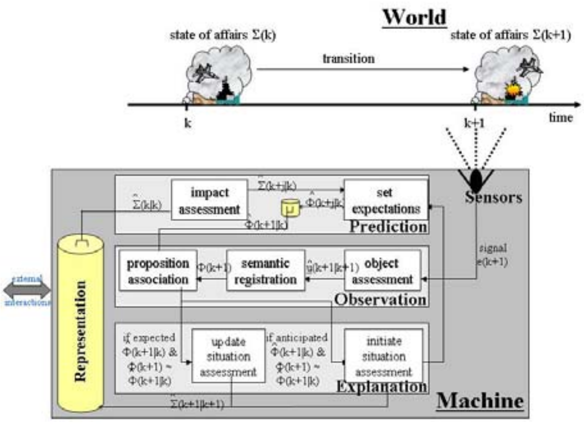

Figure 11: STDF Model for Situation Assessments

At level 2, the world is understood in terms of situations as transitions between states of affairs, with states of affairs expressed as a set of statements about the world in a formal language associated with a formal logic. The inclusion of a formal logic allows the semantics of the interpretable symbols in the formal language to be defined, or at the very least constrained. The choice of interpretable symbols in the formal language depends upon the nature of the domain under consideration.

For the military oriented North Atlantis vignette, the Mephisto framework ([12],[13],[10]) has been used to identify the basic interpretable symbols. Mephisto characterizes the world through 5 tiers and identifies concepts and associated interpretable symbols for each tier. Military events in the world typically involve all five tiers concurrently.

Social: **ally**, **agrees**, **possesses**, **commands**, …

Cognitive: **believes**, **expects**, **prefers**, **perceives**, …

Functional: **senses**, **strikes**, **informs**, **moves**, …

Environmental: **air**, **water**, **upland**, **outer_space**, …

Metaphysical: **exists**, **identical**, **before**, **connects**, …

Logical constraints specify the meaning of each of these terms. Implementation of these logical constraints then constrains the machine's interpretation of those concepts. Some implemented examples of logical constraints include:

identical(X, Y) if **fragment**(X, Y) & **fragment**(Y, X).

connects(X, X) if **exists**(X).

agrees(@(X, T, S1), @(Y, T, S2), Prop) if
  offers(@(Y, T1, _), @(X, T1, _), Prop) &
  intends(@(X, T, S1), Prop) &
  informs(@(X, T, S1), @(Y, T, S2) &
    intends(@(X, T, S1), Prop)) &
  before(T1, T).

The semantic constraints facilitate both numerical calculation and abstract symbolic reasoning. The **distance**(C1, C2, D) predicate will calculate the great circle distance D between coordinates C1 and C2. Knowing **before**(T1, T2) and **before**(T2, T3) is sufficient to deduce **before**(T1, T3), even when numerical times for T1, T2 and T3 are not known.

7.2 Observation

At level 2, observation comprises object assessment, semantic registration and propositional association (Figure 11). In the North Atlantis context, object assessments are the tracker outputs described in section 4. These are typically vectors of the form

<id, time, <x, y, v_x, v_y>, lat_ref, long_ref, P, type>

where: id is a unique identifier; time is a relative time; x is position in the x direction; y is position in the y direction; v_x is speed in the x direction; v_y is speed in the y direction; lat_ref and long_ref are the relative source reference coordinates; P is a covariance matrix; and type is a classification between air, surface, subsurface or unknown. The following is a sample object assessment vector.

```
<t_821, 7200665, <40193.1, -108826, -215.141, 209.048>,
  1.004414, -0.465357,
  <<30627.3, -4925.19, 1326.65, -154.695>,
    <-4925.19, 41766.1, -154.19, 1676.42>,
    <1326.65, -154.19, 116.128, -6.58736>,
    <-154.695, 1676.42, -6.58736, 130.768>>, 0>.
```

The semantic registration process accepts object assessments and translates them into formal sentences supported by the Mephisto framework. The following is the semantic registration output of the previous sample vector.

```
at(t_821,timestamp(2001,6,16,13.0,45.0,51.28),
        coordinate(radians(0.9873294202374645),
                      radians(0.4539469822836761),
                      (metres(0.0),metres(100000.0)))),
speed(@(t_821,timestamp(2001,6,16,13.0,45.0,51.28),_1865),
        metres_per_second(299.9778594913298)),
course(@(t_821,timestamp(2001,6,16,13.0,45.0,51.28),_1880),
        radians(2.3418315976755615)),
tell_in_air(@(t_821,timestamp(2001,6,16,13.0,45.0,51.28),
        coordinate(radians(0.9873294202374645),
                      radians(-0.4539469822836761),
                      metres(5.0E+04))),
        celtic_sea_ext*redland_region),
unknown_allegiance(@(t_821,timestamp(2001,6,16,13.0,45.0,51.
28),_3318)),
[[40193.1,-108826.0,-215.141,209.048],
  [40216.767919900805,-109061.98584052833,-
213.95539528911104,204.80762301955747], …]
```

This registers the level 1 object assessment in a form that can be reasoned with by level 2 processes. If the user wishes to receive updates on any semantically registered information, then the natural language generation code can be applied. When applied to the previous example, it generates the following output.

With some degree of uncertainty, at the time of 13.0 hours 45.0 minutes and 51.28 seconds on the 16th day of June 2001, t_821 is at location 56.56 degrees latitude, -26.0 degrees longitude, with an altitude between 0.0 metres and 100000.0 metres. It has a speed of 299.97 metres per second, has a course of 134.17 degrees, is of unknown allegiance, and is in the airspace over Redland's Celtic Sea.

English accounts of semantic registrations have previously been disseminated to the users through virtual advisers (see section 8).

Semantic registration is a value adding process that draws on considerable domain knowledge couched in Mephisto terms. Domain knowledge covers geography (both in abstract region connection calculus terms and through access to a GIS system), the capability and disposition of available forces, the political alliances, political intent, and the like.

Under the cognitive model outlined in section 7.3 below, semantically registered observations are classified as perceptions. The propositional association challenge is to reconcile the incoming perceptions with expectations and anticipations formed through the prediction process. Propositional association superficially mirrors level 1 data association in that it involves gating, prediction, scoring and assignment. Gating is used to hash candidate perceptions into different clusters, but extends beyond data association gating by providing both a logical and regional basis for gating. The prediction process gathers the candidate expectations and anticipations. In low uncertainty contexts the scoring and assignment steps reduce to unification based pattern matching. In higher uncertainty environments, in which multiple perception to expectation associations are possible, a scoring process is used to rate possible associations before the assignment process selects pairings, while possibly allowing multi-hypothesis options to proceed. Mathematics for this can be found in [9].

7.3 Prediction and Explanation

The higher-level STDF process is being implemented within the ATTITUDE TOO cognitive architecture, which has recently been written as a successor to the ATTITUDE cognitive architecture ([14]). An ATTITUDE TOO agent's long-term memory comprises: assertional memory consisting of *semantic* and *epistemic* long-term memory, and *episodic* long-term memory. The semantic memory holds the logical constraints discussed in section 7.1. The epistemic memory contains the declarative domain knowledge alluded to in section 7.2. Episodic memory consists of cognitive routines, each comprising a goal and a behavioural recipe for achieving that goal, expressed as a network of propositional attitude instructions. Semantic memory delivers meaning; epistemic memory delivers the "know that" domain knowledge and episodic memory delivers the "know how" domain knowledge.

The prediction and explanation steps are primarily managed through cognitive routines, supplemented by the assertional memory. A simplified example of a cognitive routine for monitoring a ship traversing a sea lane is featured below.

```
routine(traversing_sea_lane),
   ^(believe(i, entering_sea_lane),
    (Number_Missed_Updates is 0),
    (Max_Missed_Updates is 3),
   *(^((Number_Missed_Updates =< Max_Missed_Updates),
        add_time(When, timeperiod(0.0,0.0,0.0,1.0), Expiry),
        line_segment(sea_lane(Lane), _, Terminal),
       +(^(expect(i,
             one_of([ updated_along_sea_lane,
                         updated_across_sea_lane,
                        updated_stopped_on_sea_lane,
                        updated_enter_sea_lane_nexus]), by(Expiry)),
          +(^(not_believe(i, updated_enter_sea_lane_nexus),
              intend(i, traversing_sea_lane_nexus, priority(0.9)),
             disapprove),
            ^(not_believe(i, updated_along_sea_lane),
             desire(i, updated_along_sea_lane)),
            ^(not_believe(i, updated_across_sea_lane)
              desire(i, update_across_sea_lane)),
            ^(not_believe(i, updated_stopped_on_sea_lane),
              desire(i, update_stopped_on_sea_lane_nexus)))),
      (Number_Missed_Updates
                is Number_Missed_Updates + 1)),
      When is New_When)),
      +(^((Number_Missed_Updates > Max_Missed_Updates),
          believe(i, exited_sea_lane)),
        succeed)).
```

The example routine monitors transitions between entering_sea_lane, along_sea_lane, across_sea_lane, stopped_on_sea_lane and enter_sea_lane_nexus states of affairs. The routine illustrates expectations being set for the last four of these states of affairs during execution and these are reconciled with perceptions using the proposition association process discussed in section 7.2. This particular example uses uncertainty to perform the association process, but does not carry the uncertainty into the routine and does not pursue a multi-hypothesis approach, though both can be done. The expectation signifies the prediction process while the beliefs represent the explanation process. In that respect the routine is particularly simple. Higher order routines, such as predicting the likely final destination and time of arrival, draw on lower level routines like the one illustrated. Cognitive routines also typically deal with the interacting behaviour of multiple objects, not just a single object as in the simple illustration.

8 Higher COP

The Common Operating Picture (COP) is widely used to support situational awareness, providing a 2D 'dots on maps' display that shows where entities are located in the battlespace relative to various geospatial features – i.e. the outputs of lower-level fusion. However, the COP does not support the comprehension and projection aspects of situational awareness – the outputs of higher-level fusion systems. The COP leaves the cognitive load on the user to interpret the 'picture' displayed. Furthermore, it provides no aid to achieving 'shared' situational awareness for users in diverse roles and operating domains – how they interpret a common 'picture' will be influenced by their individual context. While the COP may be sufficient for lower-level fusion, a context-sensitive 'Higher COP' or 'HiCOP' is needed to display the outputs of higher-level fusion systems.

Establishing and maintaining context is a fundamental requirement for information fusion ([15]). Given incomplete information provided by sensors, context is a necessary consideration for object detection and classification. Context is even more important when attempting to understand (and act on) the behavior of objects in the environment, as it depends on abstractions that can not be directly measured. Failure to recognize this can inadvertently bias the interpretation of a situation – with potentially tragic consequences[2].

Context is just as important for conveying information to the users of a command and control (C2) system. If context is not clearly established, users' will need to reconstruct it from tacit knowledge, background information, and so their interpretation of a COP will depend on their current roles and situations. By clearly establishing context, users can rapidly assimilate the information provided and have a greater likelihood of: a)

[2] For example, the NATO attack on the Djakovica refugee convoy, cited in "Final Report to the Prosecutor by the Committee Established to Review the NATO Bombing Campaign Against the Federal Republic of Yugoslavia", http://www.un.org/icty/pressreal/nato061300.htm

correctly interpreting the situation, and b) sharing a common interpretation with other users.

Sensor fusion can be thought of as establishing the data about the entities in the environment, while higher-level fusion is about establishing the story behind the data. Thus, achieving situational awareness for the users of an information fusion system is akin to storytelling ([16]), which provides a compelling mechanism for describing complex and contextually sensitive relationships. Television news services provide a highly successful example of storytelling which incorporates multimedia to convey situation awareness about complex relationships in a local and global context. They establish context through the use of multimedia content such as imagery, video, and graphics, and use narrative to assist comprehension of a situation and its consequences.

The daily briefing in military command centers fulfills this role, but the scope and timeliness of these briefings is predicated on the production process. A better model would be to provide television-style multimedia 'briefings' (or 'multimedia narrative') on demand for any situation as it develops, yet it is not practical to have a television production team assembling briefings on this scale – an automated system is needed. Storytelling is generally considered to be a uniquely human ability, but there is a growing body of work ([17]) that is demonstrating how real-time animated characters can provide training outcomes similar to humans.

Figure 12: One of DSTO's Virtual Advisers

Real-time animated characters, dubbed 'virtual advisers', have been developed by Australia's Defence Science & Technology Organisation (DSTO) to act as automated storytellers that provide multimedia narrative on demand. The constrained format needed for military-style briefings provides a niche well-suited to the current technological limitations. Virtual advisers can interact with users using natural language and text-to-speech technologies, and present multimedia content. Virtual advisers can provide additional context such as importance, confidence, and urgency through non-verbal cues. Appearance, facial expressions, gestures, behavior patterns, and voice prosody can all be used to provide contextual cues to the users. Incomplete information can be conveyed by selecting different multimedia elements to represent different levels of abstraction. Trust is another important factor that influences user engagement and confidence in the information presented ([18]). It is important to manage the relationship between the users and the virtual adviser so that context can be conveyed without disrupting the users' trust in the virtual adviser.

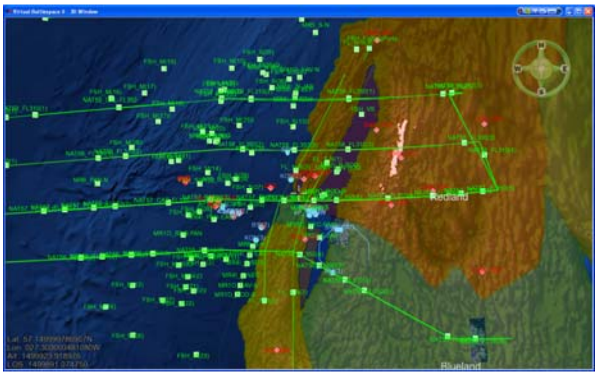

Figure 13: The Virtual Battlespace smoothly transitions to and from a 'dots-on-maps' display to a virtual reality scene when appropriate.

Figure 14: The Virtual Battlespace provides a photorealistic 3D geospatial display incorporating multimedia annotations.

Virtual advisers provide a generic capability to provide multimedia narrative that can be rendered on demand. However, for military situation awareness a capability for displaying geospatial context is also required. A "virtual battlespace" capability provides this. It is a photorealistic 3D geospatial representation of the battlespace, using real-time track feeds and digital terrain, imagery, and maps provided by web services. It can convey to the users a much richer, and up-to-date, representation of the area of operations than a traditional map. Sensor envelopes, air corridors, and engagement zones can be displayed in 3D, and multimedia annotations can be dynamically added to highlight objects and relationships of interest, and associate expansion information with the entities in the scene. This provides a rich capability for multimedia narrative when orchestrated with a virtual adviser.

Correction of errors, or content refinement after the fact as more information becomes available, is often difficult. This can be facilitated by managing the users' trust in particular content. 'Untrustworthy' characters can be used to present information where the reliability of the information is low, but the risk associated with ignoring it is high. Different media may also have implicit levels of trust associated with them: for example, text is considered a more reliable source than a virtual adviser ([19]). By selecting media with lower associated levels of implicit trust, correction of the users' situation awareness when more reliable information is available can be facilitated. To avoid unwanted associations in the Virtual Battlespace, one approach to dealing with uncertain information is to use models that are not identified with any real system. For example, an unidentified submarine could be represented by a fictitious model that bears no resemblance to any existing submarine, as shown in Figure 15 below.

Figure 15: An unidentified submarine may be represented by a fictitious model to avoid unwanted associations.

The effective use of multimedia narrative as a Higher-COP depends on the ability of a computer system to generate and assemble multimedia components to convey a coherent, informative, and interesting, message to the users. This requires, in some sense, the ability to emulate human storytelling expertise, and capture the "director's art". This is a challenging requirement, but it is important to note that the aim of this work is only to provide *some* capability to enhance situation awareness. Basic templates for layout of media, and simple heuristics for media selection, could be used to assemble a basic multimedia presentation to aid the decision makers' comprehension of the situation and its consequences.

Further refinement of higher-level information fusion and more intelligent multimedia selection and layout is required to realize an effective fully-automated system for a Higher COP. The CDIFT provides an ideal environment in which to further develop and trial these capabilities, with virtual adviser and virtual battlespace technologies playing a significant role as situational awareness displays.

In the CDIFT, summary reports generated by fusion applications, in particular the 'virtual Commander Joint Task Force' (vCJTF) agent, are published over the JTFIG. A number of report subscribers select only those reports relevant to the particular role of the site, priority and context. Based on the information content, context, and user preferences, these reports can be rendered in a number of ways: as text output; presented by the virtual adviser; or displayed in the virtual battlespace. Currently the content presented in this way includes: simple summaries of the numbers of entities observed; the probability of association of maritime tracks with sea lanes; clustering of tracks based on their kinematics; and prioritized threat assessments of air tracks. This capability will be extended and refined further as the CDIFT develops and more applications are incorporated.

Figure 16: Example of how virtual advisers and virtual battlespace are used in the CDIFT.

9 Urban Operations

One of the best environments to envision higher-level fusion is the urban environment. Urban operations push toward the limits – combining army, navy, air, joint and civil powers together, and ranging from the strategic to the tactical levels ([20]). Global urbanization over the next 20 years will create an increasingly demanding operational environment for military forces to operate in. Moreover, these areas will take on importance too, with future opponents choosing to fight in urban areas to offset tactical advantages of more sophisticated forces. Simple avoidance of urban areas because of challenges created by a multi-dimensional battlespace, and the presence of non-combatants and complex infrastructures, will not be an option in many cases. An Army must be capable of fighting and winning throughout the range of conflict and in the environment where decisive action is required. Any force that cannot operate effectively in both urban and expanded battlespaces will be severely restricted in its future responsiveness ([21]). Historical and contemporary operations implying urban environments are considered as complex if not extreme cases (e.g. Stalingrad, Hue, Mogadishu, Grozny, Bagdad, Kandahar). They implied or imply a wide range of resources from the whole spectrum of defense and civil services (plus NGO, media, etc.) and interactions at all levels of command. Even the study of counterinsurgency is closely linked with urban operations since they generally share the same theatre of operations.

The TTCP panel on Information Fusion is currently working on an extension of its basic scenario to include urban operations ([22]). The first step has been to include – almost integrally - an existing scenario developed for a Kingston Staff College (Canada) exercise held in 2002 entitled "Urban Challenge 2025" ([21]). A NATO Research and Technology (RTO) study afterward enriched it with tactical-level vignettes ([23],[24]). To define vignette enrichments, military personnel and scientists wargamed the original "Urban Challenge" scenario in more specific contexts. These contexts were limited to three mission types: crisis response operation, defensive operation, and offensive operation. All of these developed and played from a command and control (C2) point of view.

There is a work in progress to include this enriched urban scenario within the panel basic scenario story. This will most likely be translated in an ethnic based urban conflict within Whiteland implying Greyland immigrants' descendents. This group would require more autonomy for their province. The troubles would occur within urban theaters.

New iterations of the urban vignettes are already forecasted. One proposal is to include two scenarios defined by the Joint Forces Command – Urban Operations Office (US) ([25]). The first is entitled "Counterinsurgency in Port Lewis, 2015-2021". It covers a domestic counterinsurgency context resulting in bacterial meningitis and influenza outbreaks. The second is entitled "The attack on Qabus 2027". It covers a foreign urban operation context.

Finally, parallel work is currently performed to identify significant urban vignettes at the tactical level to act specifically as testbeds for higher-level fusion discussions and concepts validation. Drafted vignettes are up to now characterized by the large spectrum of information fusion possibilities they offer (e.g. from signal recognition to multi-dimension situation assessment).

10 CSAR

The combat search and rescue (CSAR) mission vignette developed at DRDC Valcartier could be easily integrated to CDIFT. This vignette was placed into a fictitious exercise scenario - Final Lance-Atlantis, which was borrowed from the Canadian Forces Command and Staff College (CFCSC). The actions of each airborne tactical platform, as well as the elements of Combined Air Operations Center (CAOC) participating in the CSAR mission, were described in detail along the sequence of events that would occur during the conduct of a CSAR mission. A particular emphasis was placed on the methods, techniques and sensors used in compiling and exploiting both a recognized air picture (RAP) and recognized ground picture (RGP) using airborne assets. Although separate elements of the same mission, many of the RGP assets are airborne and, as such, are part of the RAP. Therefore, any movement of air assets to enhance the RGP would have a concomitant effect on the RAP. A synchronization matrix of "friendly" actions and communications (directive and informative) was created, first, given the ideal situation with no enemy action and then reflecting the actions and decisions of three (3) of the following unpredictable events:

a. Event 1 - inability to locate the enemy ground positions due to cloud and terrain;

b. Event 2 - enemy attack helicopters appear in the CSAR area; and

c. Event 3 - enemy SAM systems in the enemy rear area detects the CF-18 attack mission.

Although CSAR, like SAR, is considered a single mission, it is composed of two (2) separate and distinct phases – the search phase and the rescue phase. In a peacetime SAR scenario, often the search phase is coincidental with the rescue phase. Aircraft, normally SAR capable, will be dispatched to fly deliberate search patterns over the suspected area of concern. Once the lost person(s) is/are detected, like a floundering ship at sea, and the search aircraft is capable, like a SAR helicopter, the rescue takes place immediately. However, in the same example, if the search aircraft was fixed-wing, then, with the search phase complete, the rescue mission would be launched separately.

The same concept holds true for the CSAR mission except that, due to the threat posed by conducting a rescue operation in enemy territory, the search and rescue phases of the mission are quite distinct and often are separated by days. There are numerous methods of searching for downed crews or personnel lost in enemy territory. As expected, the technique of flying a predictable search pattern over enemy territory would be fraught with risk. Combat search techniques would include:

a. location by electronic means using emergency locator transmitter (ELT) signals emanating from downed aircraft. Those signals can be triangulated by satellites like SARSAT or by aircraft flying in friendly territory;
b. location by radio/secure radio transmissions from the downed crew(s) using escape and evasion radios. These transmissions can be voice, which could pass exact GPS location or a homing signal for triangulation. Again these search techniques could all occur over friendly territory; and
c. fly tactically supported reconnaissance assets (aircraft or UAVs) through the suspected target location to

visually spot the crew(s). This is normally not done due to the risk of losing another asset and because the personnel on the ground have no way of knowing that the reconnaissance mission is friendly and thus will likely be avoiding/evading detection.

On the second day following the commencement of the Alliance joint operations to secure Blueland territory and expel any Coalition invasion forces, a UK Royal Air Force (RAF) Tornado call-sign HAWK27, conducting an electronic countermeasures and reconnaissance (ECR) mission, was shot down over the Celtic Straits by a surface-to-air missile (SAM) at 1608 hours. The crew did not report any radar activity, so it was believed that the missile was either an optically launched SA 8 or shoulder launched SA 14. Both systems had been reported in the area as part of the Coalition Airborne Regiment that invaded the Blueland portion of the Camrien Peninsula at the outset of hostilities.

The Tornado aircraft's wingman reported that both aircrew had ejected safely and that the downed crew had reported no injuries via secure communication using their survival radio. Shortly after the location of the downed crew was known, a CH-124 Sea King helicopter from Wahhabe Airbase, with a crew of five, was sent to recover and evacuate the Tornado aircrew. At approximately 1800 hours, in the process of extraction of the downed Tornado crew, the Sea King crashed. The cause of the crash is attributed to mechanical failure. Two (2) members of the Sea King crew sustained non-life-threatening injuries that have limited their mobility on foot. The crash site, illustrated in Figure 17, and location of both crews is 5650N 2740W, which is approximately 60 nm north of the Brownland town of Amitava on the Camrien Peninsula.

Figure 17: Tornado and Sea King Crash Site.

The situation was forwarded from the Combined Air Operations Centre (CAOC) to the Air Component Commander (ACC) for consideration in the Joint Force Commander's (JFC) force allocation for the upcoming planning period.

Finally, data sets, describing the individual characteristics of each of the friendly and enemy airborne assets and ground-based SAM systems found in the CSAR scenario can be provided to assist in follow-on CDIFT simulation and/or ontological modelling.

11 Conclusion

This paper outlines a collaborative program of work in higher-level fusion being conducted between Australia, Canada, the United States and the United Kingdom under the auspices of a TTCP panel on Information Fusion. The paper shows how work from the four nations has been integrated through a common scenario, which the panel proposes to subsequently offer as a benchmarking scenario for the higher-level fusion community more broadly.

References

[1] Bossé, É., J. Roy and S. Wark, Concepts, "Models, and Tools for Information Fusion", Artech House, Boston, 2007.

[2] Blanchette, M., "Military Strikes in Atlantis – A Baseline Scenario for Coalition Situation Analysis", The Technical Cooperation Panel, Technical Report TR-C3I-TP1-1-2005, 2005.

[3] Salerno, John J., Michael Hinman, Douglas Boulware, "Building A Framework for Situation Awareness", In Proc of the International Society on Information Fusion (ISIF) Conference, Stockholm, Sweden, June 2004.

[4] Salerno, John J, Michael Hinman, Douglas Boulware, "A Situation Awareness Model Applied To Multiple Domains", Proceedings of SPIE 5813, 65, Orlando, FL April 2005.

[5] Walt Gadz, Anthony Colby, and Michael Seakan. "Information Extraction for Counterdrug Applications", In 2003 Proc of the ONDCP International Technology Symposium, San Diego, CA, July 2003.

[6] Pearce, P. V., A. Robinson, and S. C. Wright. "The Wargame Infrastructure and Simulation Environment" (WISE). In V. Palade, R. J. Howlett, and L. C. Jain (Eds.), Knowledge-Based Intelligent Information and Engineering Systems, 7th International Conference, (KES 2003), September 3-5, Number 2744 in Lecture Notes in Computer Science, Oxford, pp. 714–722. Springer-Verlag, Berlin, 2003.

[7] Hossain, A., Walmsley, N., Pearce, P. “A Minimum Spanning Tree Approach to Identifying Collective Behaviour and Inferring Intent for Combat Models”, The International C2 Journal, Vol. 2, No. 2 pp. 1-33, 2008.

[8] Lambert, D. A., “A Unification of Sensor and Higher-Level Fusion”, Proceedings of the 9th International Conference on Information Fusion, Florence, Italy, 2006.

[9] Lambert, D. A., “STDF Model Based Maritime Situation Assessments”, Proceedings of the 10th International Conference on Information Fusion, Québec, Canada, 2007.

[10] Lambert, D. A., “A Blueprint for Higher-Level Fusion Systems”, Journal of Information Fusion, Vol. 10, No. 1, pp. 6 – 24, Elsevier Publishers, Amsterdam, 2009.

[11] White, F. E., “A Model for Data Fusion”, Proceedings of the 1st National Symposium on Sensor Fusion, 1998.

[12] Lambert, D A., “Grand Challenges of Information Fusion”, Proceedings of the 6th International Conference on Information Fusion. Cairns, Australia. pp. 213 – 219, 2003.

[13] Lambert, D. A. and C. Nowak, “Mephisto I Towards a Formal Theory”, Proceedings of the 19th Joint Conference on Artificial Intelligence, The Australasian Ontology Workshop, Hobart, Australia, 2006.

[14] Lambert, D A., “Automating Cognitive Routines”, Proceedings of the 6th International Conference on Information Fusion. Cairns, Australia. pp. 986 – 993, 2003.

[15] Steinberg, A.N. and G. Rogova. "Situation and context in data fusion and natural language understanding", *11th International Conference on Information Fusion*. Cologne, Germany, 2008

[16] Wark, S. and D.A. Lambert. “Presenting The Story Behind The Data: Enhancing Situational Awareness Using Multimedia Narrative”, in *MILCOM 2007*. Orlando, FL.: IEEE, 2007.

[17] Gratch, J., et al., “Creating Interactive Virtual Humans: Some Assembly Required”, *IEEE Intelligent Systems*, July/August: p. 54-63, 2002.

[18] Cassell, J. and T. Bickmore, “External Manifestations of Trustworthiness in the Interface”, *Communications of the ACM*, 12, 2000.

[19] Smith, G., M. Dry, and M. Lee. “Trust and Confidence: Presenting Information Over A Network Using Text Or A Speaking Head”, *TTCP HUM TP7 Workshop on Aerospace Human Factors Issues in Network-Centric Warfare*. White Hart Hotel, Salisbury, Wilts, UK, 2005.

[20] Glenn, R. W., C. Paul, T. C. Helmus, P. Steinberg. People Make the City, “Executive summary: Joint urban operations observations and insights from Afghanistan and Iraq”. 84 pages, 2007.

[21] Canada - DLSC. “Future Army Experiment: Operations in the urban battlespace. Directorate of Land Strategic Concepts”, Fort Frontenac, Kingston (Ontario), Canada, 25 pages, 2002.

[22] Pigeon L., É. Bossé. “Scenario consolidation for C2 urban operations S&T validation”, Defence R&D Canada Valcartier Technical Report Draft, 94 pages, 2009.

[23] NATO-RTO. “Command and control challenges in urban operations: An analysis and a system of systems study of information critical for the commander in the field”, RTO Technical Report TR-IST-046, 234 pages, 2007.

[24] Smeenk, B. “Scenario and vignette descriptions for RTO-IST 46 Command and control in urban operations”, TNO-FEL (NL) Memorandum, 18 pages, 2005.

[25] United-States - “Joint Forces Command. Joint urban operations – Joint integrating concept, version 1”, Department of Defense, Joint Forces Command, 129 pages, 2007.