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C2 framework for interoperability among an air component command and multi-agency systems

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Abstract

In an environment where there exists collaboration among armed forces and multiple agencies, ensuring interoperability among C^2 systems demands a scalable architecture that is also secure while still supportive for the discovery of newly available services. These requirements have been verified on real-life scenarios by the Brazilian armed forces, which were structured for conventional conflicts but had to face different C^2 environments when participating in humanitarian relief operations. In such situations, the tasks to be executed in a short period need to be planned from an operational view and, whenever possible, maximizing the efficiency of the available resources. Achieving these objectives while operating under a C^2 structure that was not originally designed for interoperating with the many players usually involved in such environment is a major liability to the Brazilian armed forces. This paper presents a proposal for a C^2 architecture currently being development to address this limitation. Although the research focus is on the Joint Forces Air Component, the approach might be applied to different C^2 structures. The first results showed the need for a set of measures to be adopted by the operational sector of the Brazilian Ministry of Defense, which we also address in this work.

1 Introduction

Command and Control systems exist as supporting tools for the decision makers, with the objective of speeding up the decision process while optimizing its expected results.

The existing processes within a Joint Forces Air Component (JFAC) focus on performing planning at the operational and tactical levels. The results of this effort come in the form of fragmentary orders (FRAGO's) assigned to the air units, which will ultimately produce the desired effect declared in JFACC's (JFAC Commander) intents.

The C^2 group of the Aeronautics Institute of Technology (ITA-Brazil), with support of the C^4I Center at George Mason University, is conducting research aimed to increase the current level of automation of the Master Air Operation Plan (MAOP) / Master Air Attack Plan (MAAP) process definition. The idea is to reduce the time it takes to delineate Courses of Action (COA) and to generate the respective Air Tasking Orders (ATO) and Airspace Coordination Orders (ACO).

This part of the JFAC's process is particularly susceptible to errors, especially when the commander's intent is translated into specific orders to the tactical level, a well-known source of mistakes, misconceptions, inaccuracies, and other aspects related with the semantics and the pragmatics of knowledge exchange.

The framework being proposed in this work to support JFAC's processes addresses the above-mentioned needs. Part of our initial results is conveyed in this work as a set of suggestions for the operational and strategic levels of the Brazilian Ministry of Defense (MD), which are consistent with our preliminary findings. Although we are still in the initial phase of our research efforts, our primary goal is to reach a level of framework maturity that is sufficient to ensure interoperability among armed forces and multi-agency systems.

This paper is divided as follows. Section 2 brings a high-level account of the JFAC C^2 process. Section 3 provides a brief description of related research addressing automation strategies for operational planning. In section 4, we describe the basic ideas behind our framework, including the Air Component Web Service applications and the support for JC3IEDM. Section 5 provides a case study illustrating the implementation of WS applications in a flood scenario. Section 6 provides a brief overview of the major challenges faced during the implementation of these ideas. Finally, Section 7 brings our conclusions with respect to the current state of our work.

2 JFAC C^2 Process

Upon receipt of the Operational Level Order (OPORD), which includes the COAs defined for the component forces and their respective prioritized target list, the JFACC generates the Air Operations Directive (AOD) conveying his intentions. During the release of the AOD and the definition by the Air operations Center (AOC) of the ATOs and ACOs, it is necessary to build a short-term situational awareness picture of the operations theater (OT).

This snapshot of the OT is the MAOP (NATO) / MAAP (DoD) and must contain updates of the enemy and friend forces with respect to the tasks being carried out in the next 48 hours. The MAOP / MAAP involves the low-level fusing (LLF) of diverse available data in the JFAC's C^2 systems, which results are then transformed into a consistent short-term situational awareness picture in a process called high-level fusing (HLF). However, the current state-of-the-art in HLF is still highly dependent on subject matter experts (SMEs) from the operational area, a scarce resource that makes the establishment of a MAOP / MAAP a difficult, error-prone, and time-consuming process.

In spite of these shortcomings, the interpretation of commander's intent is a crucial step for the whole process, and one that must be done by very experienced personnel who can translate the subjective statements conveying the intent into tasks to the air units. At the same time, metrics must be established to allow for a consistent monitoring of the battle.

Even the most superficial analysis of this process would uncover that a precious amount of time is consumed just to build the orders that must be issued through the ATO in a 48-hours cycle. Thus, considering the average manning restrictions for the relatively small relief operations, there is little time to plan more than one tactical COA and even less to identify whether an optimal one exists.

It should be emphasized that even if the high demand for experts to support the data fusion process could be eventually met, the process of building a MAOP / MAAP as most processes involving human cognition and complex inferential tasks is intrinsically not scalable, so just adding more manpower to the equation would not produce optimal results. As such, much can be done to improve the overall process via simulation and adding the support of HLF techniques such as the ones focused on probabilistic semantics and pragmatics (e.g. [1]). Although our work involves research on the latter, this paper is focused on the former.

As an example of the application of simulation techniques to the MAOP / MAAP process, we are developing simulations with the objective of assessing the possible outcomes from the ATO built. This is done concurrently to the built process itself as a means to improve both the quality and the efficiency of the process, although the resulting time overhead makes it preferable to conduct the simulation before the production of the ATO.

If an actual MAOP / MAAP build requires a successful interpretation of the commander's intent, its simulation demands an even greater precision since now it must be written in an unambiguous language, understandable to both man and machine. In addition to this syntactical requisite, it is also clear that a rigorous semantic alignment between this language and the terms adopted by the doctrinal body of the operational level is a nonnegotiable requirement [2]. Similarly, the description of the scenario should be clear and unambiguous so that both humans and automated systems can understand how the geospatial distribution within the OT looks like.

The OPORD conveys more information than what a simulation system requires to establish a scenario and to identify possible COAs. Also, the simulation process receives extra input from analysis performed by humans, which are still much more efficient than machines to perform this task. Therefore, both the OPORD extra information (i.e. crafted for human consumption only) and the extra input to the simulation should be stored into a repository that will allow other systems to carry out the necessary fusion with the results of actions on the battlefield.

In order to provide a suite of interoperable tools capable of generate, analyze, and evaluate COAs at JFAC level it is necessary to investigate more than one approach. At the same time, making them available in an adaptable architecture led the group to search the Web repository for similar initiatives as reported in related works.

3 Related Work

Due to the large variety of existing initiatives related to interoperability among C^2 systems and among systems and simulations, only those of most interest to the group's context are mentioned here. Initiatives such as the SISO C-BML [3] and MSDL [4] have established the initial structure supporting the interoperability among C^2 systems and simulations and are setting the standards for addressing the problem in translating the commander's intent into a simulation. The NATO Modeling and Simulation Group Technical Activity 48 (MSG-048) is evaluating a series of technologies to promote such interoperability and is conducting experiments with multinational C^2 systems and simulations since 2006.

In 2009, the MSG-048 group registered the successful implementation of an expanded BML Web service with the ability in push orders into and pull reports from simulations without humans in the information exchange loop [5]. To achieve that, they applied the Command and Control Lexical Grammar (C2LG) and a scripted version of JBML [6] to query and update a JC3IEDM database (MIP).

Addressing the framework vision at the Joint Task Forces level, Bayne and Diggs [7] established an Enterprise Command and Control (EC2) framework designed to provide DoD enterprises with shared network-accessible C^2 services. Their contribution was to define a service-oriented framework with multi-agency communities of interest in focus as tactical federations.

With respect to COAs analysis, the group is attempting to apply initiatives like [8] where it is necessary to evaluate multiple parallel COA simulations implementing the Effect Based Operations concepts. This approach is interesting because it addresses aspects such as the lack of time during MAOP process.

Other interesting approaches are being considered by ITA's C^2 group research and may be incorporated during the framework development.

4 C² Framework for JFAC

The increasing demand for C^2 systems spanning different organizational levels (strategic, operational and tactical) that are interoperable and meet the requirements of organizations with different maturity levels is a major challenge for systems of systems developers. As part of our work towards the development of a system that produces a higher degree of automation of the process of structuring the MAOP, we are investigating a framework that implements a Service Oriented Architecture (SOA) using Web Services to provide data fusion, tasking automation, security and other relevant services. Another relevant aspect we would like to mention is our use of the JC3IEDM as a data model, a decision based on our perception of an increasingly wide adoption of it by many countries.

In a common operation environment, there will be diverse organizational units and departments within the JFAC competing for resources when performing the various activities of an operational cycle. In our approach, these organizational units and departments will be posing queries through a layer that translates the orders and plans contained in an OPORD or saved in a repository. Since the JFAC may be geographically distant from the Joint Forces Command headquarters, it becomes clear that a secure network must be established. This network must have enough bandwidth to enable services to be maintained by a registry repository and easily found by the various JFAC's applications.

In spite of this requirement, eventually there will be situations in which service providers could be located somewhere outside the network, especially during operations carried out with other government agencies in a humanitarian relief operations scenario. To make sure all possibilities are properly addressed, one of the most important aspects of our research is to clarify the issues of security, bandwidth and distributed registry in such situations. This concern can be observed when analyzing Figure 1, which shows the basic structure of the framework as in its current form, established as a platform for studies of the research group.

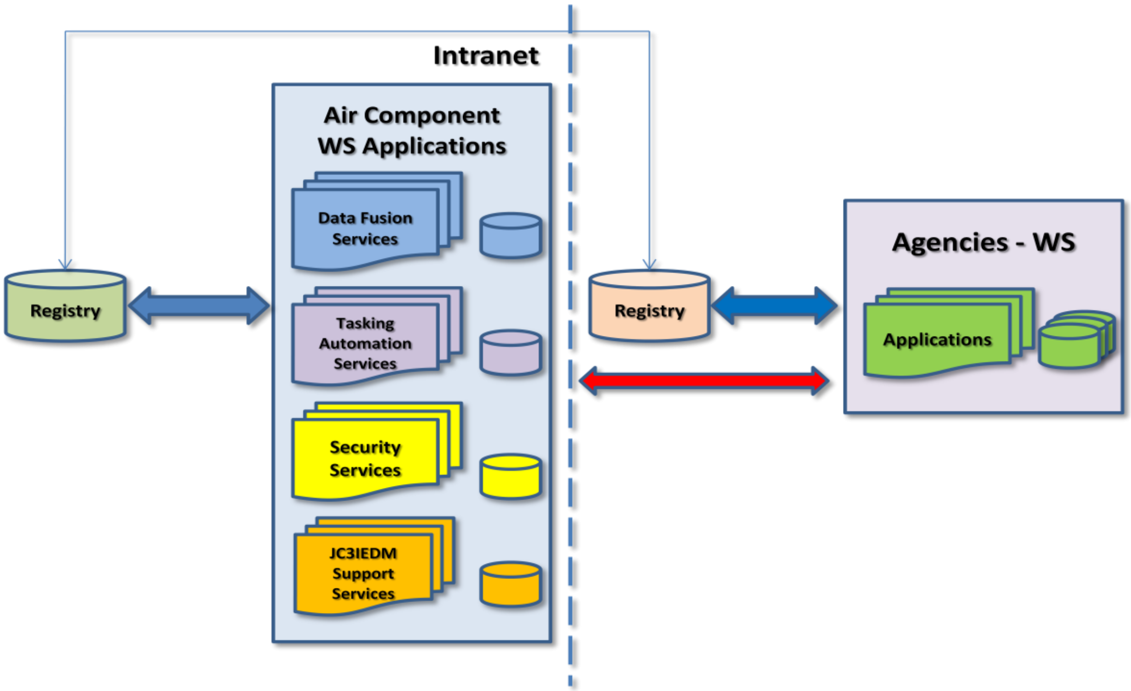

Figure 1 – High-level diagram of ITA's C^2 framework.

As can be seen in the figure, the Air Component has four types of services. The *Data Fusion Services* are used primarily for the acquisition and maintenance of situational awareness at the component level, to support the decision cycle of the commander and his staff. The *Tasking Automation Services* are responsible for supporting the MAOP construction cycle and the subsequent definition of the ATO / ACO. The *Security Services* are responsible for maintaining the access policies of the various cells within the JFAC, as well as access to common database applications. Finally, the *JC3IEDM Support Services* are responsible for the repository's integrity and availability.

Initially, the framework will employ a pure client-service-directory model of service discovery [9] with a distributed service registry. That way, the agencies' WS should find the Air Component's registry and ask for the necessary credential to access the component's services. In the same manner, the Air Component's applications should find agencies' registered WS.

4.1 Air Component WS Applications

As we mentioned before, the Brazilian armed forces were structured to respond to regular conflicts since their conception. However, due to the changing global geopolitical scenario these forces have been constantly assigned to participate in operations supporting national and international disasters. Thus, the most common scenario of application of the Brazilian armed forces will be humanitarian aid. An example of such deployments is the one currently taking place in Haiti (long before the earthquake), in which Brazil is responsible for the security of the population as one of the integrative forces of the UN mission (MINUSTAH). Other examples include the humanitarian response to the flood situation in Bolivia, as well as in several Brazilian states.

Due to its inherited structure, the Brazilian Air Force (BAF) currently adopts a JFAC structure for conventional operations and a small Numbered Air Force for humanitarian relief operations. Thus, in addition to the basic structure for air operations in conflict situations, our research is also focusing on an architecture that is capable to interoperate with the agencies that will make use of the services of a small Numbered Air Force structure to provide support in disaster situations.

The need for collaboration among BAF and agencies' systems exist because of the opportunity to achieve a better utilization of resources, to share situational awareness in areas where the agencies are working on, and to increase mutual awareness. The latter is an important factor to the agencies so that they can perceive the impact of air operations in their activities, and to the BAF as it makes the eventual users of its services better trained on its processes and requirements. These issues are crucial for humanitarian relief operations, where resources are always scarce and often underutilized due to a lack of coordination at various levels.

Access to data of interest should occur through the air component services where the security criteria must be satisfied. So, the air component applications are being developed to provide the necessary information based on the characteristics of the operation, by means of service composition models.

Our approach has two different models of service composition:

- An orchestration mechanism that interprets the component business model and generates the service composition that is most relevant to each pre-established scenario;

- A dynamic composition algorithm to be utilized in conjunction with Semantic Web Services (SWS) to provide the composition based on a Domain Ontology [10, 11].

The two proposed structures utilize basically the same services, but the interoperability requirements are different because the BAF component in such operations (i.e. a Numbered Air Force) must share information with other agencies that are working at the same operational area. These agencies are usually neither at the same network infrastructure nor at the same network structure, and are most likely adopting different protocols and policies.

4.1.1 Data Fusion Services

In a decision-making process following the basic OODA loop, the Observe, Orient and Decide phases are heavily supported by data fusion systems. The main goal of the Data Fusion Service Layer is to increase the collaboration among C4I systems already developed and being utilized by the force component cells. The general approach is to use the SWS as a framework to build simple services that share information through ontology mapping technologies and making them available to other interested systems.

In addition, our group is currently pursuing a method to facilitate JDL's levels 2 and 3 data fusion [12] utilizing the information and services available via the framework, including simulation services' output at the Tasking Automation Services layer.

4.1.2 Tasking Automation Services

As explained when describing the JFAC process, the MAOP is a key aspect in the whole process. Therefore, we have opted to use the Tasking Automation Service Layer as the framework's first study case.

The goal is to provide a COA's scored list based on established metrics derived from JFACC's intent. Our basic research hypothesis is that it is necessary to simulate the COA's possibilities before the construction of ATO / ACO to increase the efficiency at the force component level.

This service layer encompasses the following services, among others:

- OPORD commander's intent BML extraction;
- OPORD scenario MSDL extraction;
- Metrics and OPORD restrictions table extraction (Prioritized Target List – PTL, available resources, apportionment, etc.);
- COA's BML/MSDL description;
- COA's simulation;
- COA's scored list construction;
- ATO/ACO construction;
- Database support;

The main process input is the OPORD and its output is the ATO / ACO. The simulation service is intended to be reusable outside the actual force component process. Therefore, the possibility of considering a COA BML/MSDL description as input allows for evaluating an ATO, as well as for trying to anticipate the enemy intent. In both cases, the service has the ability to deliver relevant information about the scenario evaluation.

The COA's scored list is an opportunity to aggregate the human expertise, because some relevant information may not be available in the OPORD before the simulation running and this service shall provide a way of adjusting each COA for another trial.

4.1.3 JC3IEDM Support Services

The JC3IEDM Support Service layer is a series of services which main purpose is to query and update all the information based on the JC3IEDM data exchange format. Many applications will use the JC3IEDM database and the group is currently assessing the better approach to maintain the database integrity while making its data available according to the different demands the applications will have. The first results of these studies are described in [10], while our current focus is on how to extend it to include the capabilities introduced at the BML effort described in [5, 6, 13, 14].

5 A Flood Scenario Study Case

As discussed before, the most common involvement of the Brazilian armed forces outside conventional military operations occurs in the form of humanitarian relief operations. To reflect this fact, we chose as a case study the 2008 Santa Catarina flooding [15], where the whole Itajaí´s valley was completely flooded for a month and an enormous effort took place to provide assistance to the affected population. During this event, it was necessary to mobilize a small Numbered Air Force to ensure efficient coordination of the air transportation assets and to establish a supply corridor in order to receive the medical supplies, food and clothes to the affected population.

Based on the relevant information about the events, we introduced a small ontology that will be the domain descriptor and will be used to establish the basic concepts present in the semantic service descriptions. Figure 2 brings a partial graphical depiction of the ontology used in the study case scenario.

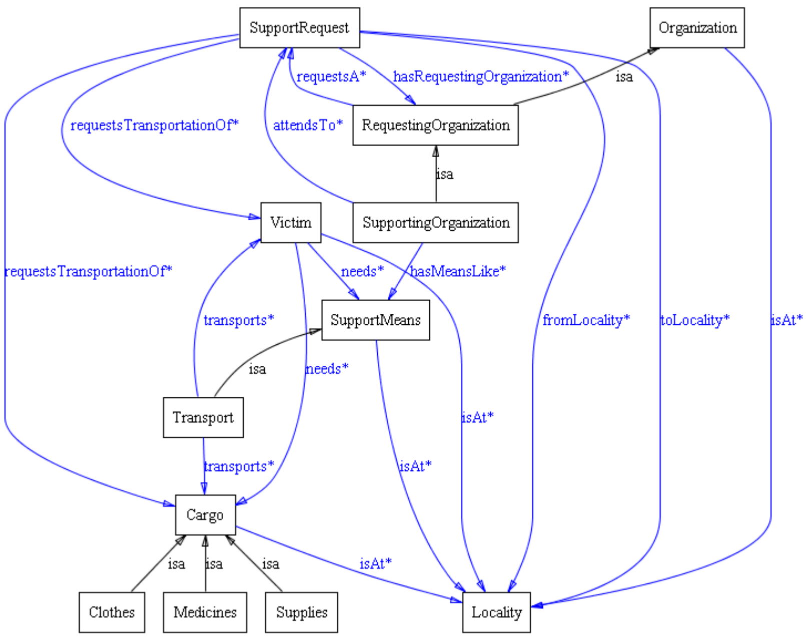

Figure 2 – Flood Scenario Domain Ontology.

The implementation was made in J2EE platform with web services architecture. The main goal of the application is to make available to all organizations involved with the flood situation the following: available assets (ground-based, fluvial and aerial); location of all support installations; field solicitations for rescue missions and transport of supplies; and the schedule of the assets movement throughout the affected area.

The framework was implemented by assigning the Support Requests to the agencies' WS and the tasking automation of the solicited air transport inside the affected area to the JFAC´s WS. Establishing a parallel with a Joint Operation, the Central Assets Coordinator can be viewed as the Combined Joint Task Force Commander (CJTFC), who will receive all requests and will coordinate and prioritize all the available assets, sending to each component its prioritized request list with all the locations, cargo to be delivered, and time to accomplish each goal.

Under this scheme, the air component is expected to receive its assigned requests and plan its missions accordingly. To achieve this in a real context, the component should have a means or process to change the planned missions in real time due to the nature of these operations, in which a life saving sortie will always take precedence over a cargo mission. Due to the complexity of the operations in this case study, our initial efforts to validate the framework have neither utilized a real time planning process nor a real time WS. Both cases will be subject of future analysis and research.

After planning the missions, the produced ATO / ACO will be available only for the air component through WS, and the routes and scheduling will be available outside the component´s intranet, sharing the operational picture with the interested agencies.

6 Challenges of the Intended Architecture

The architecture is being developed within an academic environment. Thus, one immediate challenge is to ensure synergy and coherence among the distinct projects related with this effort. As a result, we are still in a stage in which a complete version of the framework is being developed, although a reasonable number of its components are already reaching a reasonable level of maturity.

Another challenge is to define the grammar to be used in Portuguese for BML implementation. This is especially difficult given the nature of the effort, which is much more doctrinal than scientific and thus poses an extra obstacle for the implementation of the framework.

The development of security services is also being performed under a strong non-academic aspect, as we must identify and make assumptions about the need to interoperate with systems of multiple government agencies and nongovernmental organizations.

The last major aspect we are addressing in our research is the definition of the ontological framework that will support the discovery process of the various services, including those that will be added later through a non-hierarchical topology of services. This involves research on the use of upper ontologies such as UCore [16], PR-OWL

[17], and others, in conjunction with domain ontologies to support the various aspects of HLF within command and control systems.

7 Conclusions and Future Work

The framework depicted in this paper is an academic effort to aggregate the state-of-the-art technologies for C^4I systems interoperability in conjunction with simulation. The first results provided a positive indication that it is possible to devise a framework to establish a common architecture for the Brazilian Ministry of Defense (MD) using Semantic Web Services. As an initial result of our current study, we have established a set of recommendations to the MD. Even though a more detail description of these recommendations is outside the scope of this work, they can be summarized as the assignment of multi-services committees that will have the responsibility of establishing (1) the Portuguese BML's grammar for commander's intent, and (2) the security policies necessary to provide access for multi-agency systems that will interact with the armed forces in non-conventional operations.

At the time of this writing, our next major task is to produce a series of developments to generate simple WS applications for tasking automation and data fusion in first place. We expect the interoperability tests with the actual C^2 systems to produce evidence on how resilient and capable is the framework.

References

[1] Costa, P.C.G., Zeigler, B., Hieb, M., and Laskey, K.B., "Probabilistic Ontologies and Pragmatics For Complex Systems Integration", 15th International Command and Control Research and Technology Symposium, Santa Monica, CA, USA, 2010

[2] Schade, U. and M. Hieb, "Formalizing Battle Management Language: A Grammar for Specifying Orders", *2006 Spring Simulation Interoperability Workshop*, IEEE Spring Simulation Interoperability Workshop, Huntsville, AL, 2006

[3] Blais, C., K. Galvin and M. Hieb, "Coalition Battle Management Language (C-BML) Study Group Report", Paper Presented at IEEE Fall Simulation Interoperability Workshop, Orlando FL, 2005

[4] Simulation Interoperability Standards Organization, SISO-REF-015-2006. "Military Scenario Definition Language (MSDL)": SISO, September 2006

[5] Pullen, J., M. Hieb, S. Levine, A. Tolk, and C. Blais, "Joint Battle Management Language (JBML) - US Contribution to the C-BML PDG and NATO MSG-048 TA," Paper presented at IEEE European Simulation Interoperability Workshop, June 2007

[6] Levine, S., M. Pullen, M. Hieb, C. Pandolfo, C. Blais, J. Roberts and J. Kearly, “Joint Battle Management Language (JBML) Phase 1 Development and Demonstration Results,”Paper presented at IEEE Fall Simulation Interoperability Workshop, Orlando, FL, 2007

[7] Bayne, J., Digg, D., “C2 in the Joint Task Force (JTF) Enterprise”, 2006 Command & Control Research and Technology Symposium, San Diego, CA, June 2006

[8] Gilmour, Hanna, McKeever, Walter, “Real-Time Course of Action Analysis”, 10th International Command and Control Research and Technology Symposium: The Future of C2, McLean VA, June 2005.

[9] S.A.H. Seno ET AL, “Survey and new Approach in Service Discovery and Advertisement for Mobile Ad Hoc Networks”, International Journal of Computer Science and Network Security (IJCSNS), VOL. 7, No.2, February 2007

[10] Almeida, Johanlemberg Ferreira de. “A model for alignment of command and control systems”, Master Thesis. ITA, São José dos Campos, SP, BRAZIL, December 2009

[11] Júnior, Frederico Guilherme Alvares de Oliveira. "A QOS-based approach for dynamic web service composition." Master Thesis. ITA, São José dos Campos, SP, BRAZIL, September 2009

[12] A. Steinberg, C. Bowman, and F. White, “Revisions to the JDL data fusion model”, In Proceedings of SPIE Conf. Sensor Fusion: Architectures, Algorithms and Applications III, volume 3719, pages 430-441, April 1999

[13] Pullen, J., M. Hieb, and S. Levine, “Using Web Service-based Command and Control to Support Coalition Collaboration in C2 and Simulation”, 13th International Command and Control Research and Technology Symposium, Bellevue, WA, 2008

[14] Pullen, J. et al., “Adding Reports to Coalition Battle Management Language for NATO MSG-048,” Joint SISO/SCS European Multiconference, Istanbul, Turkey, July 2009

[15] 2008 Santa Catarina Floods in Wikipedia. http://en.wikipedia.org/wiki/2008_Santa_Catarina_floods Last visited in april 5th 2010.

[16] Smith, B., Vizenor, L., and Schoening, J., “Universal Core Semantic Layer”, Proceedings of the 4th Conference on Ontology for the Intelligence Community (OIC 2009), Fairfax, VA, USA, 2009.

[17] Costa, P.C.G., and Laskey, Kathryn B., “PR-OWL: A Framework for Probabilistic Ontologies”, Proceedings of the Fourth International Conference on Formal Ontology in Information Systems (FOIS 2006). B. Bennet and C. Felbaum (eds.), Baltimore, MD, USA, November 9-11, 2006, pp. 237-249.