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Distributed Simulation with Automated Planning: Study and Support Tool for Relief Operations in Conflicted C2 Scenarios

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Abstract

Every year, floods and droughts affect thousands of people that directly or indirectly are dependent on public initiatives. However, governments have been shown to be partially or totally incapable of properly reacting to these disasters. Highlighted among the many reasons for this is the lack of effective planning and situation awareness in scenarios where different support teams are working at the same area without coordination. In this context, simulations may be utilized to increase the planners' understanding of a given situation and provide a way to avoid the common mistakes that occur during resource allocation in such situations. The present work is being conducted to establish a distributed simulation environment, with 3D visualization, to support resource allocation planning and to increase the situation awareness. This approach may help managers, planners and operational people understand the scenario evolution while increasing the command maturity in such complex endeavor.

Introduction

Relevant portions of the Brazilian population are often hit by natural disasters. Over the past 10 years, it is estimated that eight million people were affected by floods and droughts across the country [EM-DAT, 2013]. For instance, one may emphasize the rains in Santa Catarina [SANTA CATARINA, 2009], the flooding in Cubatão, São

Paulo [G1 SANTOS, 2013], and the mudslides in the mountainous region of Rio de Janeiro [BBC, 2011].

In this context, different disasters have been exposing various gaps in the National Civil Defense System [SINDEC, 2009a, 2009b; BRAZIL, 2010a, 2010b, 2012] and various deficiencies on the responsiveness of municipalities and States.

Among them is the lack of an effective command structure in response to natural disasters results in a situation in which different organizations take individual actions without exchanging information or sharing resources. As an outcome, we have redundant resource allocation, inefficiency, and difficulty to support the needs of the community in those circumstances.

As an effort to assuage the aforementioned shortcomings, the Federal Government usually engages the Army, Navy and Air Force in order to assist the Civil Defense Authority, State Military Fire and Police in the operation coordination, or even to have full control in the most serious cases, also providing logistical support [AEROVISÃO, 2009; AGÊNCIA FORÇA AÉREA, 2010].

However, according to the NATO NEC C2 Maturity Model [NATO, 2009], what prevails, due to the lack of an effective structure of command, is a Conflicted C2 (Command and Control) maturity level of command. At this level, there is no awareness of each other's actions, and the restricted resources become less effective and are allocated with low efficiency.

Nevertheless, to increase the command maturity level it is imperative to have the ability of partitioning the operational space, avoiding adverse cross-impacts between the organizations or, even better, having a collaborative planning process with some coordination among the participants.

Taking into consideration that sharing the common intent is a key element in mature command and control systems, this research devises a distributed simulation environment to support the planning phase and after action review (AAR) of conflicted C2 scenarios during relief operations.

The hypothesis to be validated is the expectation of increasing the awareness, when generating pre-planned missions, of different organizations that are not aware of

each other's actions, through the use of simulation. By generating a collaborative solution with 2D and 3D visualizations, integrating the different perspectives of each organization's plan into a fused view, it is possible to have and share the big picture as a common operational picture.

The expected result is to increase the organizations' ability to share resources and to improve their synergy, allowing them to better manage their available resources in Conflicted C2 operations. Additionally, the simulation is expected to provide a valuable tool for an effective after action review, which may provide a clear picture of the past operation to the planners.

Lastly, we consider it reasonable to emphasize that this research is in progress, and its first step is to generate the simulation environment, which is the main focus of the present paper.

In order to contextualize the reader, the paper is structured as follows. The first section highlights some of the related work under the perspective of Operations Research and Management Science (OR/MS) and Humanitarian Assistance and Disaster Relief (HA/DR). Section 2 describes the framework being developed to increase awareness during planning. Section 3 presents a case study developed and based on a real case, in the State of Santa Catarina – Brazil, in 2008, and Section 4 concludes the work with considerations and final remarks.

1 Related Work

Operations Research and Management Science (OR/MS), Humanitarian Assistance and Disaster Relief (HA/DR) and C2 may be analyzed as somewhat similar research areas in terms of management focus, decision making process and logistical and operational environments. Therefore, some of the OR/MS and HA/DR papers that specifically focus the Disaster Operations Management (DOM) may be highlighted as related work.

[ALTAY and GREEN, 2006; SIMPSON and HANCOCK, 2009; and GALINDO and BATTA, 2013] have worked to provide a relevant review of significant

research on Disaster Operations Management (DOM). Hereupon, it is possible to identify several different approaches through the analysis of the three mentioned works.

For instance, we find works investigating management of evacuations [ABDELGAWAD and ABDULHAI, 2010; CHEN and CHOU, 2009; CHEN and ZHAN, 2008; CHILDERS, VISAGAMURTHY and TAAFFE, 2009; CHIU and MIRCHANDANI, 2008], disaster management [COPPOLA, 2011; IFRC, 2010; LETTIERI, MASELLA and RADAELLI, 2009], logistics [CHANG, TSENG and CHEN, 2007; NAGURNEY, YU and QIANG, 2011], decision making and decision support systems [BARKER and HAIMES, 2009; CHIU and ZHENG, 2007; SNEDIKER, MURRAY and MATISZIW, 2008].

However, even though OR/MS and HA/DR are academically connected by DOM as a common field of study, few articles related to Command and Control and Distributed Simulation could be found in the aforementioned domain [ALTAY and GREEN, 2006; SIMPSON and HANCOCK, 2009; GALINDO and BATTA, 2013]. This omission, therefore, generates a clear gap in the capacity of non-military agencies for managing HA/DR operations.

Therefore, looking towards a supporting tool which enables the analysis of Conflicted C2 scenarios and provides motivation to rescue team managers, the research is working on a proposed framework that is able to generate HA/DR scenarios.

2 Framework to Study Conflicted C2 Scenarios

Considering the dynamic nature of C2 operations, we decided to make use of simulation tools to support 2D and 3D visualization of the scenario evolution, during and after relief operations, in a fused view. This is expected to allow an enhancement of the situational awareness of several organizations involved in the planned missions and an effective after action review.

Thereby, considering simulation as a tool to help phenomena understanding, we started to look at available tools that may support the proposed framework by modeling the aspects of interest.

2.1 Distributed Simulation

Many COTS tools are available to develop the devised framework. However, due to an existing agreement with VT MÄK [VT-MÄK, 2012] in the collaborative testbed between the C4I Center, at George Mason University (GMU-USA), and the C2 Lab, at Instituto Tecnológico de Aeronáutica (ITA-Brazil), the chosen tool was the VR-Forces® [VT-MÄK, 2012] simulation tool.

VR-Forces® provides tools for C2 scenario generation and visualization in air, land and maritime environments, giving us the necessary flexibility to model different situations. The distributed aspect of the architecture provides the ability to exchange multiple plans as a set of simulation logs or individual scenario files to be merged, allowing different sites to visualize, in the same federation, plans from different organizations, within a common terrain database.

Such a feature increases the awareness of potential conflicts between plans and also the perception of when the organizations can collaborate with another one by sharing its resources for different tasks. It is then possible that one organization takes the responsibility to support the other's mission due to its resource's capability.

Finally, as we are building each federate as an organization's plan, by means of distributed simulation protocols, it is possible to display all plans together and to identify the mutual interference during the federation execution.

2.2 Inference Model to Support Planning

The proposed approach is a way to give us an answer about how uncoordinated actions may affect the organizations´ ability to achieve the overall goals during the relief operation, and what can be done to enhance synergy and efficiency.

Therefore, if we would like to support a future coordination team we should have methodologies to improve the planning process. Since the coordination between

many different organizations is an overwhelming activity, it is essential to recognize and consider the way each organization behaves during such circumstances.

Considering the difficulty of generating different plans, based on the diversity of an organization's operational procedure, the framework uses a semantic approach based on ontologies.

The use of ontologies gives us the ability to describe a domain of interest with relations and rules between the concepts. The developed Task Ontology is represented by the yellow knowledge base (KB) in Figure 1. It is the result of different interconnected ontologies that together convey the knowledge about the scenario. The main usage of the KB is for planning purposes but it also serves as the basis for situation awareness tools. The ontology was developed as the result of the research described in [MARQUES, 2012].

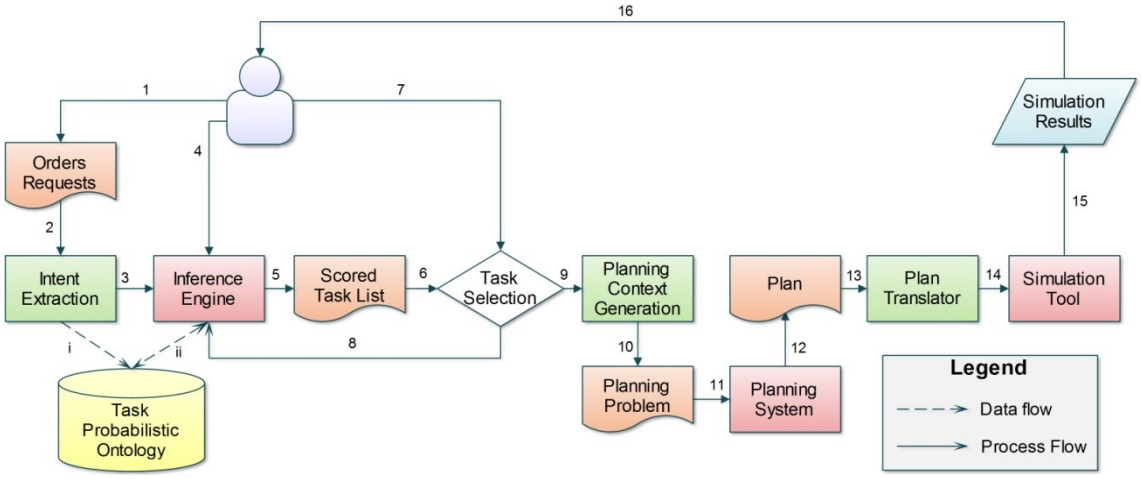

Figure 1 - Inference model to support plan automation. Source: [MARQUES, 2012].

To model higher level effects and to convert them into lower level task decompositions, we found the need to develop a task ontology that has principled support for probabilities.

The Task Ontology is not a closed ontology as it can be extended according to the purpose of planning. Because of that, it is also possible to describe the uncertainty inherent in C2 scenarios; like the probability of a location to be flooded, the status of

people to be rescued, the weather condition in the near future and the availability of each resource based on each domain (air, land and fluvial).

2.2.1 Ontology Description

The overall ontology has the $\mathcal{SHOIQ}^{(D)}$ expressivity and is composed of five sub-ontologies: Domain Ontology, Planner Ontology, Scenario Ontology, PR-OWL Ontology and the Task Ontology. They are written in OWL with the PR-OWL extension [COSTA, 2005] and the connections between sub-ontologies are formally described.

In order to identify the missions that are capable of producing an effect, we have modeled relations in the ontology as depicted in Figure 2. Such relations are deterministic and support inferences such as determining which type of mission we can task in order to achieve the desired effect. However, we are not able to infer through the deterministic description, how likely we are to achieve the desired effect when that task is executed.

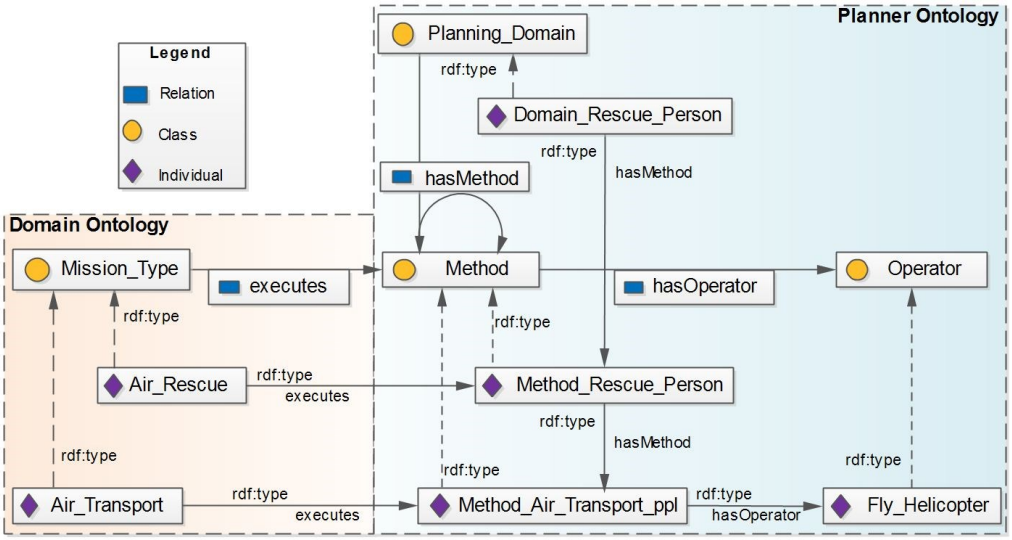

Figure 2 – Relations between concepts from the Domain and Planner ontologies. Source: [MARQUES, 2012].

Figure 2 also shows the relations between the Domain Ontology and the Planner Ontology. The type Air_Rescue mission is being related by the Executes relation with the method Method_Rescue_Person. Such a connection describes the method to be used during the planning part of the methodology.

The uncertainty has to be described through the probabilistic part of the ontology, based on PR-OWL descriptions of the random variables. For brevity, we will not give more detailed explanation of the probabilistic description in the ontology, but it can be found in the work of [MARQUES, 2012]. In short, it is used for the description of the uncertainty present in the scenario of interest. By describing the possible states of random variables that express the belief of a given concept, we are able to query the knowledge base about a specific situation.

2.2.2 Inference Process Description

Given a set of orders, or requests, and through a set of queries on the Task Ontology the output is a set of tasks that have an associated probability of success to achieve the desired effect. After choosing among the possible tasks, if one, or more than one, can be found during the available timeframe, the set is sent to a planning system that will be responsible to find a plan, if one can be found.

The inference process is responsible for generating the task list. After the task selection, each organization's plan is generated. Each plan is then translated into the simulator syntax and executed as a federate into the distributed simulation environment.

It is interesting to highlight that the most important ontologies of the Knowledge Base are the Domain Ontology, Task Ontology and the PR-OWL Ontology. The KB can only provide its outputs if the scenario is completely described. Because of that, the main work is to establish the KB in such a way that we are able to determine the resource allocation and based on each organization's criteria and doctrine.

The implementation of the inference module supporting the resource allocation is based on two different reasoning procedures. The first one is based on the deterministic part of the ontology that will map the requests and determine the possible resources that are capable to support the tasks for each request. The second one is based on the probabilistic part of the ontology that will receive each possible resource allocation and will take into account the uncertainty present in the scenario.

Figure - 3 shows the information flow during planning, as carried out by the component Planning System in Figure 1, based on the reasoning process' output. In the

present research, the planning system is based on a Hierarchical Task Network (HTN) approach that generates a plan as a result of a sequence of actions to be taken, instead of a sequence of states to be reached. The importance of that is because we are interested in identifying the interaction between actions during the scenario run, not specifically the resulted state.

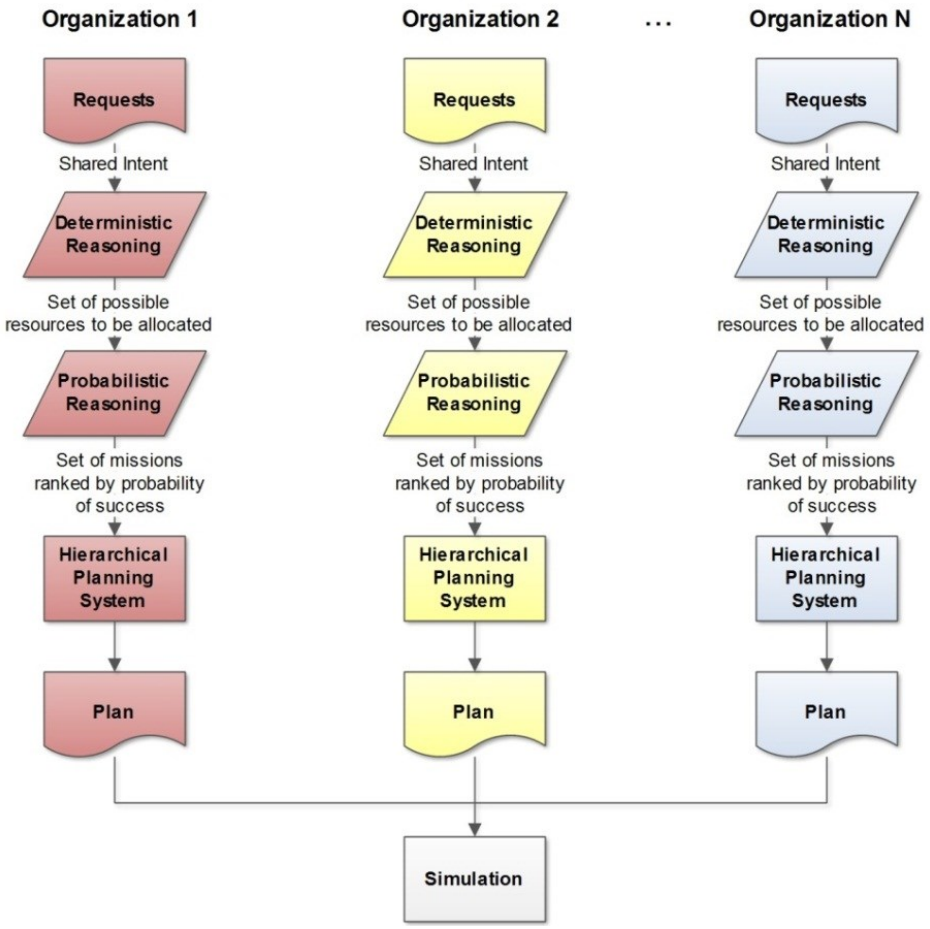

Figure - 3 Proposed planning process information flow.

The resulting plans of each involved organization are sent to the simulator, and the simulator visualization tool can show the actions being executed during the simulation run. Such a capability gives to the coordinators the ability to understand what would happen during the planning phase. Therefore, it is expected to provide conditions to increase their situational awareness and to improve the overall efficiency in terms of resource allocation.

Figure 4 presents the HTN Method_Rescue_Person indicated in Figure 2. The method is declared as a task with preconditions and subtasks. This method declares that, in order to rescue a person, it is necessary to assign a helicopter, embark the person on it, fly the helicopter from the person's location to a defined place and disembark the person from the helicopter when the place is reached. Note that the helicopter allocation is another method that has to be decomposed into an allocation operator and another operator to send the helicopter to the person's place that has to be rescued if it is not already there.

The planning output is then sent to the simulator tool after a parsing procedure to convert the planner's syntax to the simulator's syntax.

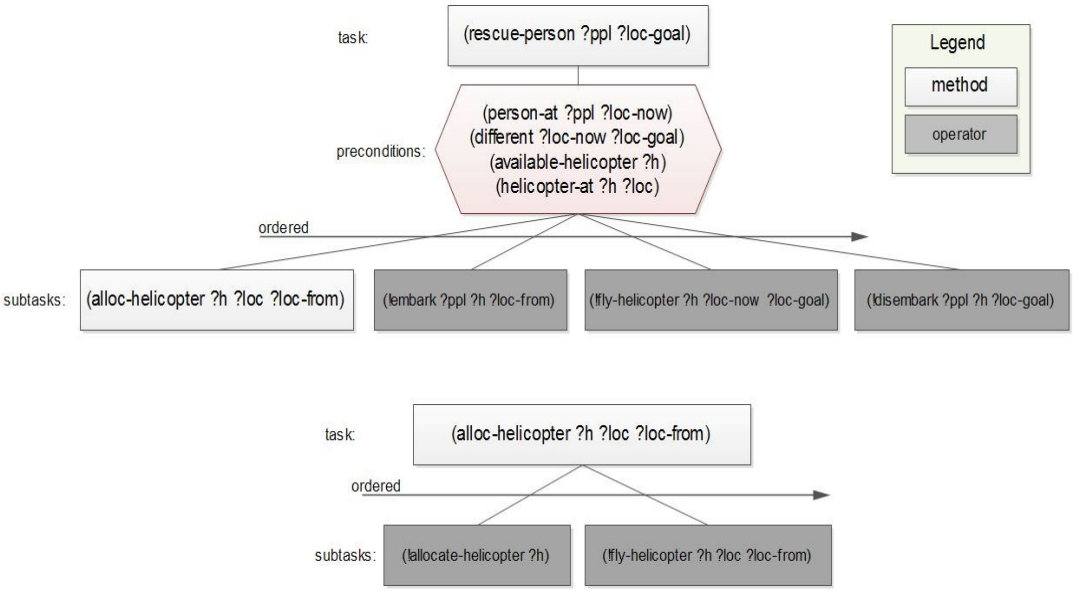

Figure 4 – Method rescue-person in Hierarchical Task Network description. Source: [MARQUES, 2012]

3 Case Study

Aiming to show the framework applicability we studied the situation in the State of Santa Catarina, Brazil in 2008, when heavy rains occurred in a short period, generating flooding and landslides in the Itajaí valley region.

At that time, 8 million people were affected by the flooding in the entire State and a massive effort was launched in order to help the victims. Many different

organizations and about twelve thousand collaborators were engaged in the relief operation.

However, because of the sudden devastation caused by the Itajaí River flooding, which was at about 10 meters above its normal level, the local residents could not flee in time, increasing the panic and the need to provide transportation by any available means [SANTA CATARINA, 2009].

For study purposes, the considered scenario will start with a flood of 2 meters, causing a small impact on the local population. As a consequence, only small groups will need to be evacuated. In terms of simulation's parameters, only people and available resources are able to perform actions and to move through the scenario. The terrain was modeled with few buildings to enhance the simulation performance and to facilitate the planners' comprehension.

The simulation is being tuned to be used in a Brazilian Conflicted C2 operation, where State Military Police has helicopters for search and rescue (SAR) and vehicles for security patrols, State Military Fire Department has vehicles and boats for SAR, Civil Defense Authority virtually has no assets and Armed Forces may have all of the previously mentioned resources.

We have divided the resource allocation into three main domains: air, ground and fluvial. Each federate represents a resource being allocated regarding a domain (e.g. air resource corresponds to air federation). By doing this, we have a simulation federation with three federates that describe the plans executed in a specific period of the relief operation.

Figures 5, 6 and 7 show three views, each one about a distinct federate before entering the federation. All federates use the same terrain of Itajaí Valley in the specific period of the scenario evaluation in order to avoid correlation problems.

Figure 5 shows the air domain plan, with many different places to be visited in order to rescue and to transport people. The blue helicopters' avatars show the location of each helicopter. The green avatars show people on the places to be visited by the helicopters. Red lines are the air corridors to be used during flight, avoiding mid-air

collisions when executing the missions. The corridors are useful because such scenario also models low visibility conditions caused by rain.

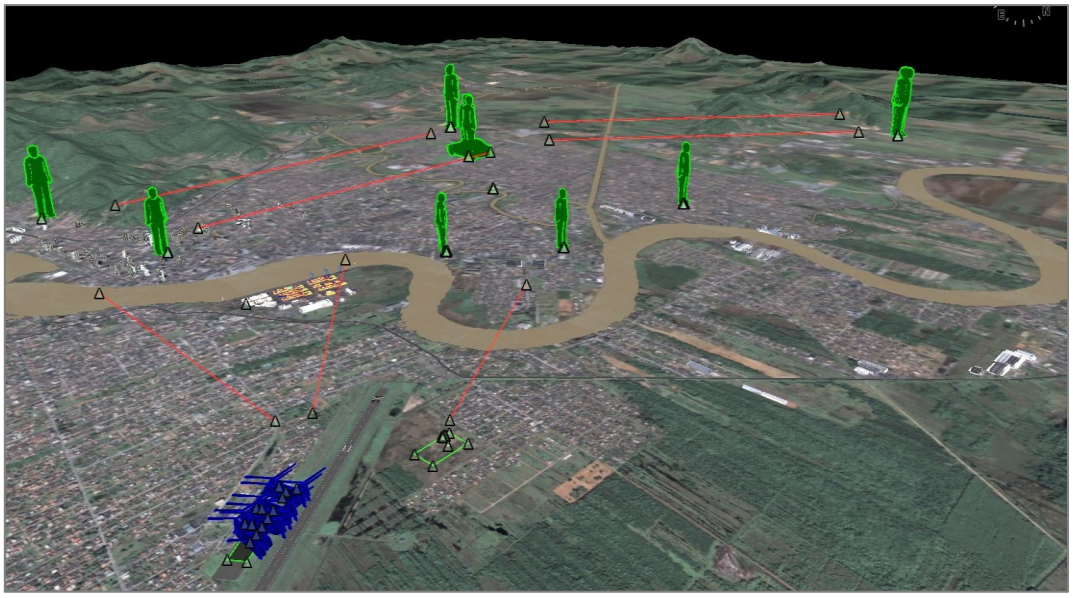

Figure 5 – Federate showing the air domain with the air resources allocated to the rescue and transportation missions.

Figure 6 provides the ground domain plan, with trucks as resources to be allocated and only one place to be visited, on the right corner of the picture.

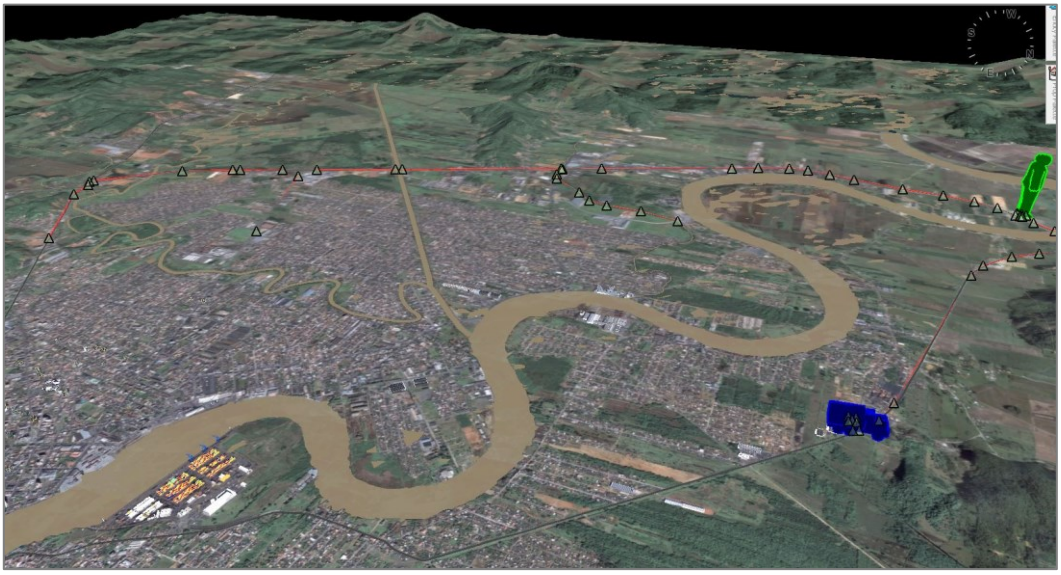

Figure 6 – Federate showing the ground domain with the ground resources allocated to the rescue and transportation missions.

Figure 7 provides the fluvial domain plan, with two different boat types as resources to be allocated and two places to be visited, on the up right corner of the

picture. We also have routes described by the red lines, pointing out the ability of the boats to follow those paths.

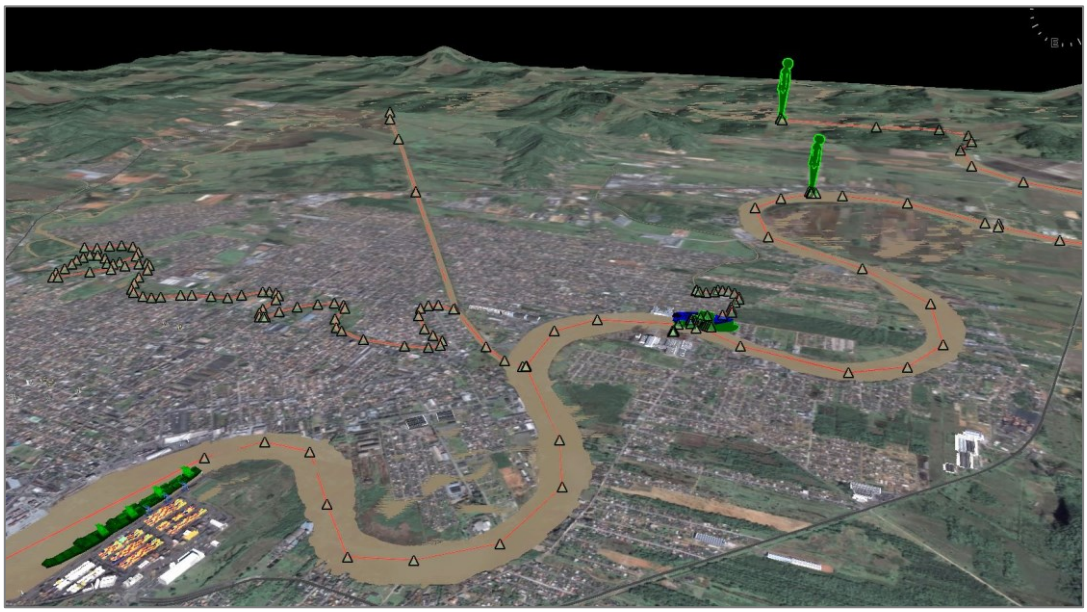

Figure 7 – Federate showing the fluvial domain with the fluvial resources allocated to the rescue and transportation missions.

Figure 8 provides the federated visualization of the domain plan, with all resources to be allocated as the integrated planning view. The figure also shows the simulation being executed and giving the ability to identify possible path conflicts, inefficient resource allocation, the overall time to complete all the rescue missions and, as the main contribution, ways to understand the impact of the conflicted command and control structure.

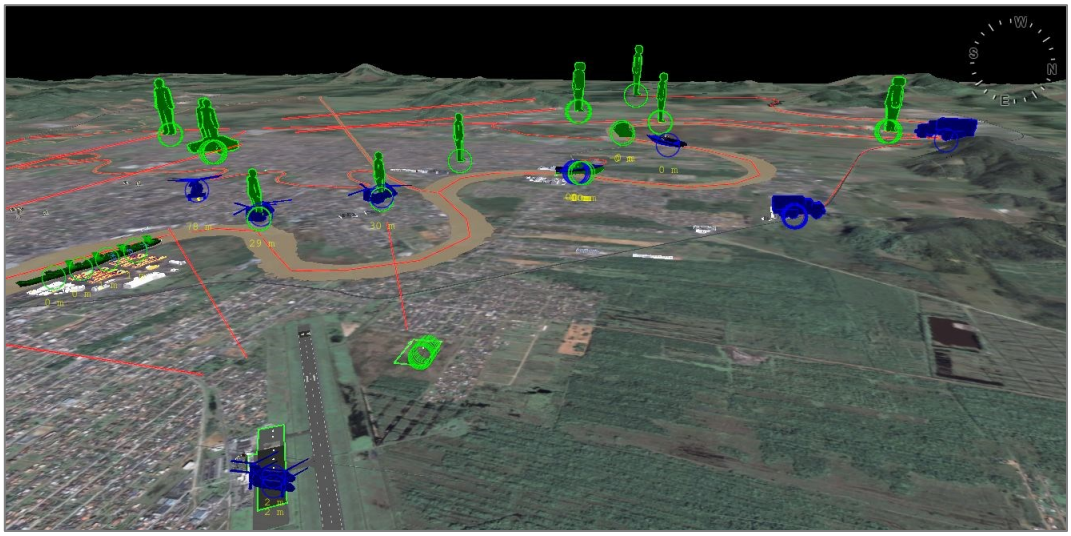

Figure 8 – Simulation federation running with air, ground and fluvial resources executing rescue and transportation missions in expanded reality (3D).

The simulator may use multiple terrains, being changed according to the simulation time. Therefore, the study team could identify the differences between the possible resources to use while the river level increases.

Figure 9 shows the 3D visualization of the environment, providing different perspectives to improve the overall understanding of a specific situation.

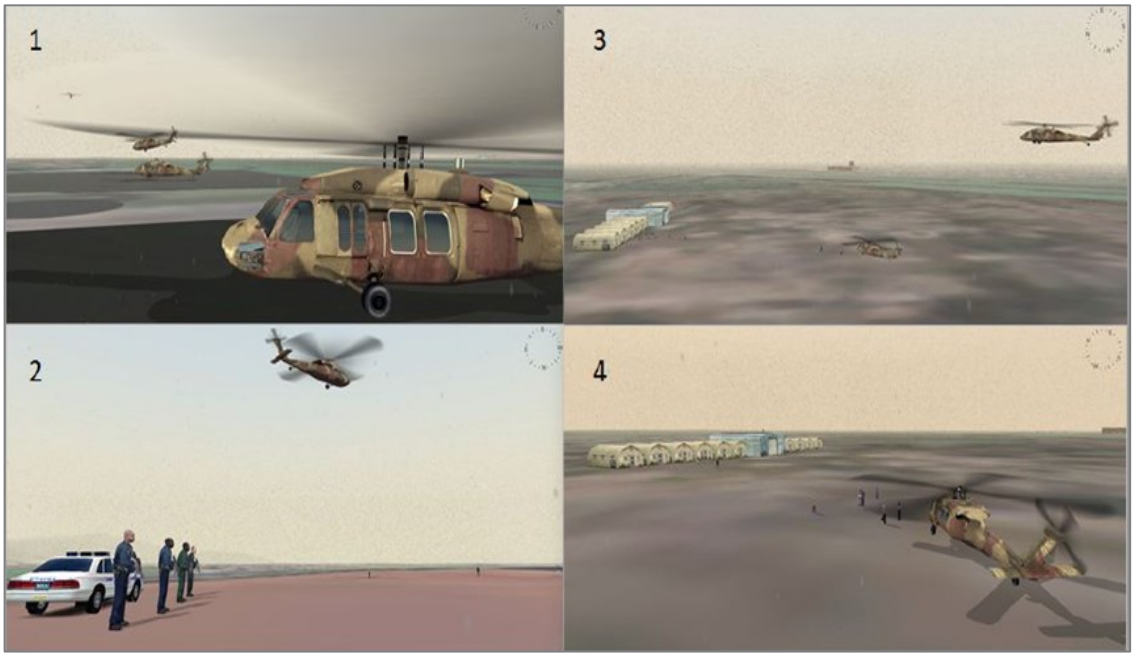

Figure 9 – Simulation federation running and showing the air resources executing rescue missions during rainy conditions. Source [MARQUES, 2012].

Figure 10 depicts the helicopters' paths, showing the necessity of the air corridors to support path deconfliction. The path history shows all visited places and possible collaborations between organizations. Such collaboration may occur when a resource, that will pass close to the place to be visited by another resource type of another organization, may take the responsibility to execute the mission, giving the opportunity to use the other resource in another place that was scheduled to a posterior time.

The visualization tool can serve as shared plan visualization or an after-action review tool if populated with historical data.

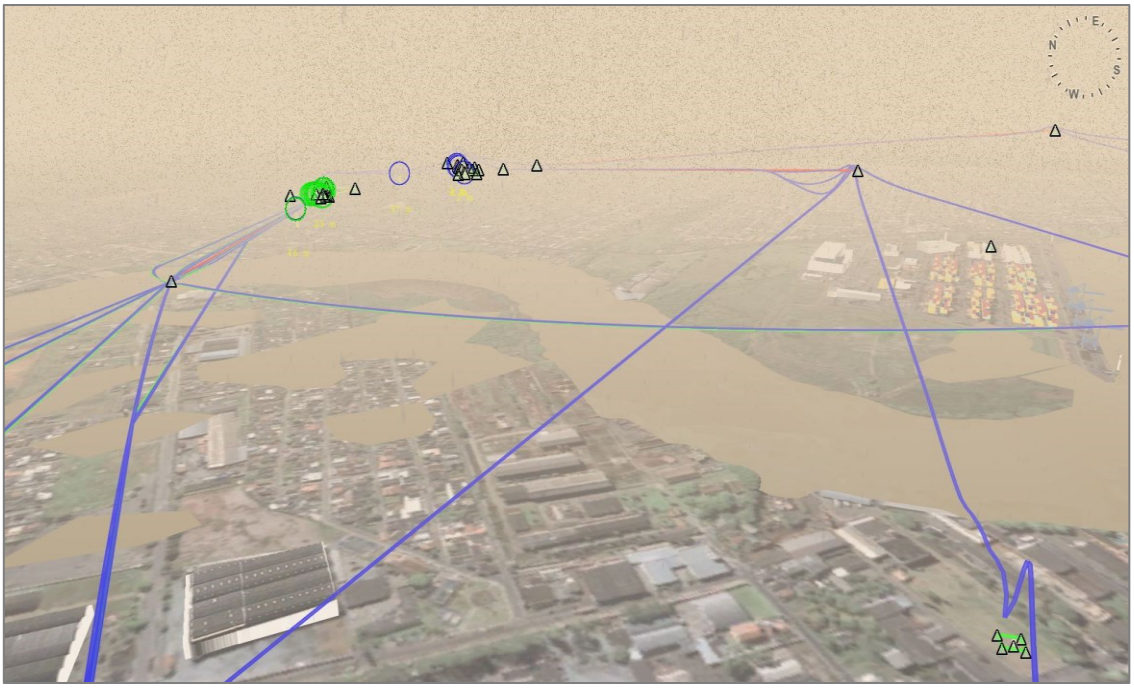

Figure 10 – Helicopters' paths during simulation execution.

4 Considerations and Final Remarks

The present work is being conducted to provide a framework to support the study of Conflicted C2 operations, focusing on HA/DR operations. The aforementioned framework uses an inference model based on ontologies, able to describe the differences between the missions that each organization can perform based on its resources.

In order to provide a set of tasks to be executed through simulation, the selected missions are sent to a planning tool, generating a hierarchical plan. Each organization generates its own plan and then sends it to a distributed simulation environment. The plan execution is made into a federate and integrated into the overall federation.

The terrain is common to all federates, and the federation execution allows someone to analyze the resource allocation and to perceive the possibilities to improve synergy, by identifying possibilities of collaboration between organizations.

The framework is able to show different perspectives that are usually hard to understand during the planning phase. By using such a tool, coordinators may have the ability to see the scenario as a whole, perceiving the misuse of resources due to the lack

of communication between organizations and also the resource utilization in regions that will be affected before the mission could be accomplished.

As an additional outcome, the simulation provides a better visualization of the resources' tracks, giving to the coordination team the ability to understand the possible path conflicts and the necessity to create air corridors during the scenario evolution, which is quite hard to get by only using conventional maps and pictures.

This simulation tool can be also used to reproduce the whole operation, serving as a useful after action review tool, which can improve the lessons learned process.

The case study is being conducted based on a real situation, and the preliminary results indicate that the approach can be utilized to support coordination teams to understand what happens in a Conflicted C2 environment during HA/DR operations.

One of the future works is to create a more detailed mission, evolving a scenario which reproduces the previous condition of 2008, where 80% of the Itajaí City was totally flooded. Another one is to evolve the Task Ontology to be more general about HA/DR operations.

Finally, another course of action is to establish some measures of performance in order to quantify the improvements. After a preliminary analysis, we chose the number of duplicated assets per task, the total number of launched missions, and the average waiting time for rescuing people, as we have considered these hard to compute and required to predict the total number of saved lives.

Acknowledgments

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