MODELING, INTEROPERABLE SIMULATION AND SERIOUS GAMES AS AN INNOVATIVE APPROACH FOR DISASTER RELIEF

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ABSTRACT

This paper presents the use of Human Behavior Modeling for Disaster Relief and Emergency Management. The authors propose an innovative MS2G (Modeling, Interoperable Simulation and Serious Game) using Intelligent Agents to reproduce a complex scenario used for Verification, Validation and Accreditation of the approach. The case study is inspired to South Sudan situation and to the necessity to provide accommodations, food, health care services, security and administrative support to a large number of IDPs (Internally Displaced Persons) over a wide area. The simulator includes camp preparation and installation, air drops, logistics network creation while the model includes populations, entities and units as well as different equipment (e.g. cargo planes, helicopters, ground units, etc.).

Keywords: Disaster Relief, Emergency Management, Human Behavior Modeling, Interoperable Simulation, Serious Games, Training

1. INTRODUCTION

Nowadays the geopolitical and economic situation is leading to a large number of critical events where a huge number of people is forced to move and needs to be supported. These conditions are generating large amount of refugees and IDPs. Indeed the term IDP (Internally Displaced Person) is introduced in reference to someone forced to abandon his home without leaving his own country; these people are often referred as refugees even if they are not corresponding legally to this current definition (Weiss 1955). In facts a refugee is a person forced to leave his own nation and unable to return home safely (Bouchet-Saulnier et al. 2002).

Obviously there are legal definition for the terms that have been approved by United Nations along the years.

Therefore the current number of refugees is estimated around 15 million while IDPs overpass 37 millions worldwide; this corresponds to a total of over 50 million people that need support on global scale (UNHCR 2015a). In table I it is proposed a synthesis of the situation as summarized in recent years and, even if the quantities are just estimations and often controversial, it is evident the complexity to address these issues (Wiki 2016).

Table 1: Overview of Global IDPs

Country	*Cause*	*IDPs*
Azerbaijan	Nagorno-Karabakh War	600,000
Afghanistan	NATO vs. Talibans Fighting	166,000
Myanmar	Internal Conflicts and Natural Disasters (Cyclones)	503,000
CAR	Civil War	197,000
Chad	Proximity to Darfur and Civil War	178,000
Colombia	War among Government, FARC, AUC & other Groups	4,000,000
DR Congo	Second Congo War	1,500,000
Cote d'Ivoire	Civil War,	709,000
Cyprus	Cyprus and Turkey Tensions	208,000
Ethiopia	Natural Disasters, Ethiopian-Eritrean War, Ogaden Conflict	200,000
Georgia	Displacement of Ethnic Georgian Population from Abkhazia and South Ossetia	260,000
Haiti	Haiti Earthquake and the resulting 575 camps for IDPs	390,000
Iraq	Wars since Saddam's Regime Fall including ISIS fighting	4,000,000
India	Kashmiri Pandits from Jammu and Kashmir fighting with Separatist Movement and Fighting between the Naxals and the Indian State	150,000
Indonesia	Fighting Government vs. Secessionist Rebels	275,000
Israel	Bedouins	10,000
Kenya	Riots and Violence after the Elections (2007)	325,000
Kosovo	Effects during Kosovo War.	590,000
Kurdistan	Kurdish-Turkish Conflict	3,500,000
Mexico	War on Drugs	925,000
Palestinian Territories	Internally Displaced Palestinians	320,000
Pakistan	Conflicts in different Regions (e.g. KP province)	400,000
The Philippines	Fighting between the Government and Communist and Islamic Rebels.	300,000
Serbia	Results of Kosovo War	220,000
Somalia	Civil War	260,000
Sudan	Civil War (South) and Darfur Conflict (West)	5,500,000
Syria	Syrian Civil War	7,600,000
Uganda	insurgency of the Lord's Resistance Army	869,000
Ukraine	War in Donbass	1,300,000
Zimbabwe	Political Violence, Major Land Reforms and the Economic Collapse	760,000

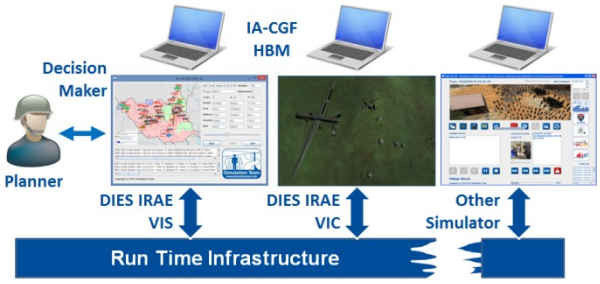

Figure 1: DIES IRAE Architecture

It is evident that these situations includes also natural disasters that have a huge impact such as Haiti Earthquake (January 2010) resulting in over 1.5 million IDPs (Billiam 2010) during the event and over 300'000 people that are still homeless after 6 years. These phenomena affect also developed countries as confirmed from recent disasters in Italy that generated, respectively, over 50'000 (April 2009) and 4'500 (August 2016) homeless in central part of the Nation (Povoledo & Mele 2016).

2. MODELING DISASTER RELIEF

In disaster relief is crucial to develop methodologies and techniques to support planning of operations and to evaluate impact of decisions. The areas to be addressed, in most of the cases, in the above mentioned examples are related to several aspects including among others:

- Logistics
- Health Care
- Food Distribution
- Engineering
- Services Activation
- Infrastructure & Equipment Deployment
- Security & Defense

Therefore in these contexts the situation is usually very complex due to infrastructure collapse (e.g. economic, transportations, food chains, etc) and to the presence of multiple actors (e.g. refugees/IDPs, local population, conflict actors, supporting coalitions, NGO). Often these actors have conflicting interests, sometime they are even fighting at level of organizations (e.g. war or civil war) or socially (e.g. ethnic tensions, social tensions). It is evident that due to these reasons the scenarios are very complex and require the use of simulation to be properly studied and to support the decision making process (Anderson et al. 2007; Werker 2007; Bruzzone & Sokolowski 2012; Latek 2013).

The complexity of these scenarios is further reinforced by the heavy impact of human factors affecting social, ethnics, tribal, religious and political issues. These elements are often the main factors to be considered such as in recent conflicts ongoing in Africa and Asia (Johnson & Mason 2008, Bellamy et al. 2011; Dewachi et al. 2014). In facts the HBMs (Human Behavior Modifiers) include psychological factors (e.g. fear, stress, aggressiveness, etc.) as well as primary needs (e.g. food, security, health care) based on the local hierarchical priorities (Maslow 1943; Møller & Schlemmer 1983; Longo et al. 2005; Saati et al. 2011).

In general it emerged that the use of Human Behavior Models could be pretty effective to reproduce the people reactions and to measure the effectiveness of the disaster relief actions (Uno & Kashiyama 2008; Bruzzone et al 2014a). These elements strongly affect the behavior of conflict actors, humanitarian supports and population as well as local and domestic public opinion (Gartner & Segura 2008; Kreps 2010). The authors acquired good expertise in modelling critical situations such as country reconstructions, disasters and emergencies (Bruzzone &Massei 2010). Several experimental cases have been conducted by Simulation Team in this sector including Haiti Simulation based on use of interoperable IA-CGF (Intelligent Agents Computer Generated Forces) and CAPRICORN Project (CIMIC And Planning Research In Complex Operational Realistic Network) on CIMIC (Civil Military Cooperation) carried out in Afghanistan. These are a valuable base to further develop innovative models (Bruzzone 2013).

In the current paper, it is proposed the use of IA-CGF NCF (Non Conventional Framework) simulator named *DIES IRAE* (Disasters, Incidents and Emergencies Simulation Interoperable Relief Advanced Evaluator) composed by two simulators. The general architecture is similar to SIMCJOH structure (Simulation of Multi Coalition Joint Operations Involving Human Modeling) as presented in Figure I (Bruzzone et al. 2015). Indeed *DIES IRAE* adopts MS2G (Modeling, Interoperable Simulation and Serious Game) Paradigm (Raybourn 2012; Bruzzone et al.2014b) and it is composed by two main simulators federated by using HLA (High Level Architecture):

- **DIES IRAE VIS** (Virtual Interoperable Simulator): is a stochastic discrete event agent driven simulation using the IA-CGF for reproducing HBM; it simulates the actions of components, equipment, units and population. This module supports operation planning, commander training, policy analysis and review of procedures and processes.
- **DIES IRAE VIC** (Virtual Interoperable Commander) is a Virtual Simulator using Serious Game approach that provide the Synthetic Environment to reproduce the events and takes care of the detailed dynamics (e.g. air drops, landing, etc) such module allows to provide support for tactical training and education.

Indeed the solution guarantees maximal flexibility by adopting interoperable HLA: in this way it becomes possible to combine the proposed simulators also with other models. This approach enables the stand-alone use of *DIES IRAE VIS* without Virtual representation or to combine it with *DIES IRAE VIC* and other models addressing specific aspects (e.g. economics, war gaming, CIMIC, etc.) in a distributed simulation. In addition, this simulation might be combined with other ones in order to be active part of a complex CAX (Computer Assisted Exercise).

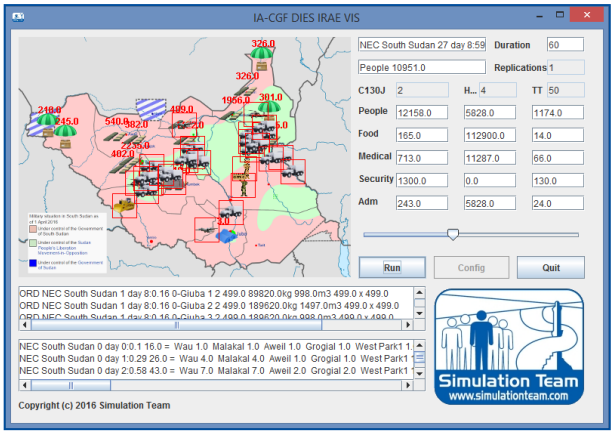

Figure 2: DIES IRAE VIS: The Discrete Event Stochastic Simulator

DIES IRAE VIS (see fig. 2) allows to simulate the operations and phenomena evolution in order to evaluate efficiency and effectiveness of the disaster relief plan. In facts, the Discrete Event Stochastic Simulator provides estimation of times, costs and availability of resources respect the demand. The model reproduce the flow of IDPs and refugees and their needs in terms of:

- Accommodation
- Food & Water
- Health Care
- Security
- Administrative Procedures

Each of these issues requires, potentially, to establish infrastructures to be deployed on site (e.g. camps, airstrips), consumables to support the operation (e.g. food packages) and resources (e.g. soldiers and medical doctors). The simulator reproduces the logistics of the operations from major hubs, to local Hub and HQs establishment, force deployment, transportations and material handling. The simulator considers to use both naval cargos, aerial solutions including helicopters and planes as well as ground vehicles (Bruzzone et al. 2002). The delivery and deployment could be carried out by conventional deliveries and/or air drops. Entities simulated include military unitis, NGO, paramilitary, civilians, IDPs, Refugees, Local Authorities, etc.
The Intelligent Agents drive the entities and the people on the scenario based on their perception and considering human factors (e.g. stress, fatigue, fear, hunger, etc)
In *DIES IRAE VIC* the IA are in charge of applying the disaster relief plan based on logic sequence, available resources and dynamic evolution of the boundary conditions (e.g. security, weather, availability of resources). The population model consider the *Interest Groups* and *People Objects* (Bruzzone 2013). Indeed the *Interest Groups* represent the different entities on the area and are interconnected by relationships identifying the intensity and type of their mutual attitude through multiple parameters.

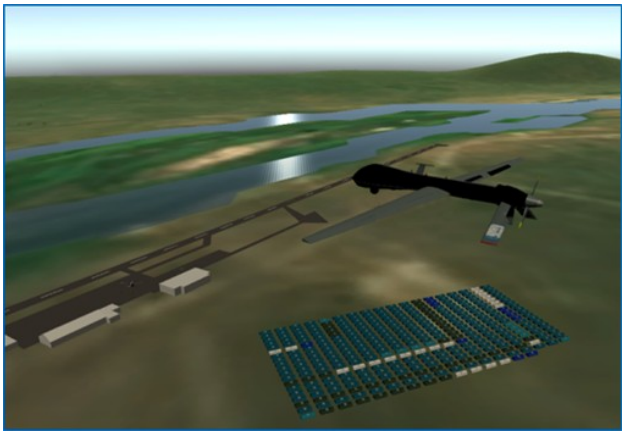

Figure 3: DIES IRAE VIC: Synthetic Environment and Virtual Simulation

Vice versa, each *People Object* reproduces a small group and its basic characterization including, among others:

- Gender
- Age
- Health Status
- Education
- Social Status
- Religion
- Ethnics
- Tribe
- Political Orientation
- Stress
- Fear
- Fatigue
- Aggressiveness
- Resilience
- Trustiness

The *People Objects* are interconnected by their social network through compatibility algorithms and are connected with the *Interest Groups* as well. They are also associated with the terrain, if appropriate, respecting geosocial characteristics of the area.
The *DIES IRAE VIS* allows to virtually reproduce these operations both in terms of observation of scenario evolution within the virtual simulator or interactive control of specific equipment as a Serious Game (e.g. conducting an Air Drop, Delivery on an Air Strip, Reorganizing a Camp). An example of the interface is proposed in figure 3.

3. SCENARIO: SOUTH SUDAN

In order to evaluate the capabilities of DIES IRAE Simulation the authors decided to identify a scenario that could be used for the VV&A (Verification, Validation and Accreditation),
Based on a preliminary analysis of the existing situation, it resulted that the current South Sudan situation could be an inspiring scenario. Indeed this reality represent a good example of modern crisis of the African continent after colonialism (Chatterjee 1993).

Figure 4: South Sudan Localization

3.1. The Context and the Scenario

All African countries became independent in the second half of the 20th century. Although some countries became independent in the 1950s, most of Africa was decolonized during the 1960s.

However, after independence, some of these states found themselves powerless against armed conflicts requiring trained, combat seasoned forces and quality equipment (Ciekawy 1998).

Some turned to UN requesting intervention to support local forces in internal or inter-state conflicts to ensure regional stability. In this context, International Coalitions started to conduct overseas operations (Murphy 1996).

During the 2000s, the European Union became a full-scale actor for peace and security in Africa, developing the African component of the European security and defense policy from 2005 (Smith 2015).

Humanitarian assistance provided in recent years by non-governmental organizations (NGOs) in Africa has saved hundreds thousands of lives; moreover, NGOs now collaborate with military forces in the delivery of humanitarian supplies.

3.2. Disaster Relief Planning in Humanitarian Operations and Commanding Officers

The above mentioned elements raise questions about the diverse range of operations and their capacity to address various needs (Pettit et al 2005).

Indeed the use of military forces to support humanitarian operations has grown along last decades to be almost commonplace in today's world.

A key objective must be to define workable doctrines for this involvement and to make commanding officers aware of the social, political and economic impact they may have with different modalities of commitment (Caunhye et al.2012).

Some of the questions to be addressed are proposed hereafter:

- How are military forces and their assets deployed in humanitarian operations?
- Which deployment models are commonly used and which doctrines need to be developed for each?
- Are the current roles effective and, if not, which roles are effective?
- How can military units be committed to peacekeeping or humanitarian operations without violating their neutrality?
- How can foreign military commanders best coordinate with civil relief authorities?

3.3. Scenario Definition

Based on the previous consideration, the proposed scenario proposed is South Sudan and its currently acute humanitarian crisis. In this country, emergency level of food insecurity is evident due to the on-going conflict (Pantuliano et al. 2008; Rai et al. 2012; Johnson 2014; UNHR 2015b; Kegley et al. 2015; Zambakari 2015).

Despite progress in the political situation following the formation of the Transitional Government of National Unity, the economic decline, depreciation of the South Sudanese pound and the sporadic violence continue to have a significant impact on the humanitarian needs within the country.

Clashes between government forces and an armed group are reported all around the country. The rapid decline in the food security situation and distribution raises fears an escalation of the crisis.

In this chaotic situation United Nations Security Council is:

1. Expressing its deep concern about the ongoing escalation of insecurity and the continued rise in violence in South Sudan as well as the persisting political impasse in the country,
2. Condemning strongly the increased cases of human rights violations and abuses and underscoring its deep concerns on further decline in the food security and nutritional status of the population,
3. Welcoming the decision of the Secretary-General to deploy a military contingent in Western Bahr el Ghazal (WBeG) region to support population and NGOs in the area.

3.4. Area Overview

Whit a surface area of 93,900 square km is one of the largest among the other South Sudan regions; according to the last population census has an estimated 333,431 inhabitants, with Christians and Muslims being the largest groups.

The source of livelihood for its inhabitants was subsistence farming, supplemented by small-scale cattle rearing and petty trading.

There was tensions triggered by boundary disputes now escalated into conflict due to rivalries over grazing land and ethnic/religious reasons. The situation is presently evolved in a humanitarian crisis, in particularly in Wau and Jur River counties refugees continue to arrive spontaneously.

3.5. Contingent Integrated Structure

The Contingent planned for testing the simulator is based on the organization proposed in figure 5 and requires the deployment of 1,450 people.

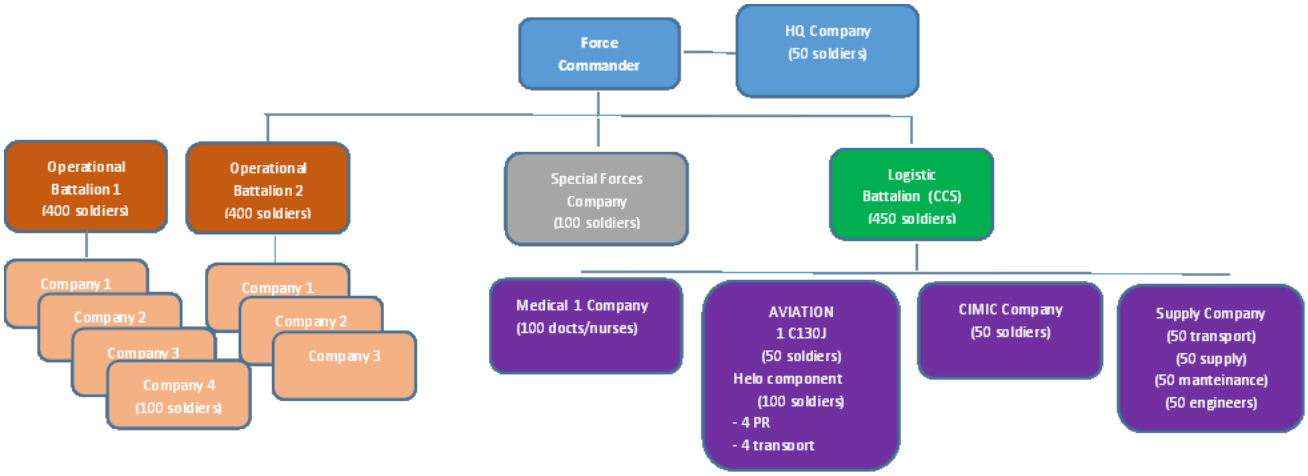

Figure 5: Contingency Structure

The organization includes C130J Planes and UH-60 Helicopters as well as UAV (Unmanned Aerial Vehicle) and ground vehicles.

3.6. Mission Mandate

With the population suffering from a humanitarian crisis that caused several thousand and to support the U.N.'s Food and Agriculture Organization (FAO), a multinational military contingent is planned to be deployed under UN mandate aims in a humanitarian operation to establish protected zones in south Sudan. The aim is also to interpose between two warring parties and to control areas.
The mission core: stability operation to restore a peaceful situation in order to supply, maintenance operations, deployment and distribution, health service support (HSS), engineering and logistic services.

3.7. Simulated Phases

The following phases have been planned

1. **Deployment**: Port Operations is Djibouti, Airport of operation is Djibouti. Port and airport capacity determines the flow of materiel into area of operations.
2. **Transports**: Air transport permits the rapid deployment and movement of personnel and cargo to, from and within area of operations and provides tactical mobility for all mission elements.
3. **Mission**: support to enable access for humanitarian personnel and relief goods, followed by medical operations and the provision of material relief goods (such as tents, clean water and food supplies.

3.8. Multinational Logistic Planning & Timelines

The Multinational Logistic Planning is expected to follow the following schedule, the simulator will check the feasibility to respect the timelines.

Day X	contingent arrive in Djibouti
X+1	SF, 1 and 2 Company (1 BTG) and Engineers Company in OA (operation area): secure area and prepare logistic (1 flight C1230J – 1 flight transport Helo);
X+2	3 and 4 Company (1 BTG) and HQ troops in OA: complete secure area and establish C2 capability (1 flight C1230J – 1 flight transport Helo);
X+3	CIMIC Company
X+5	Medical Company
X+7	FOC (full operational capability)
X+30	Sustainability

3.9. MEL/MIL & Simulation

In this context, the following MEL/MIL (Main Event List / Main Incidents List) are proposed to be considered and evaluated by using simulation:

3.9.1. MEL/MIL 1: Transport

In a deteriorated road network, military supply (Class I subsistence/food) convoys, the greatest logistics challenge depend on the number of transportation nodes and conveyance modes involved:

- Scarcity of vehicles (especially those capable of carrying refrigerated cargo)
- Limited space container area

Increase in fuel consumption (Class III petroleum, oils, and lubricants):

- Difficulties to maintain scheduled transport
- Self-sustainment just vouched for a reduced time

3.9.2. MEL/MIL 2: Hospital

Theater Hospitalization Capability delivers health support required to medically sustain forces in the JOA. Hospitalization capabilities in the JOA deploy as modules:

- Lack of full modules capabilities reduce role 2 availability and operational readiness of critical equipment (Class VIII major end item)
- According to medical plan, three technicians and one laboratory assistant must perform mass inoculation and provide logistical support for the local authorities

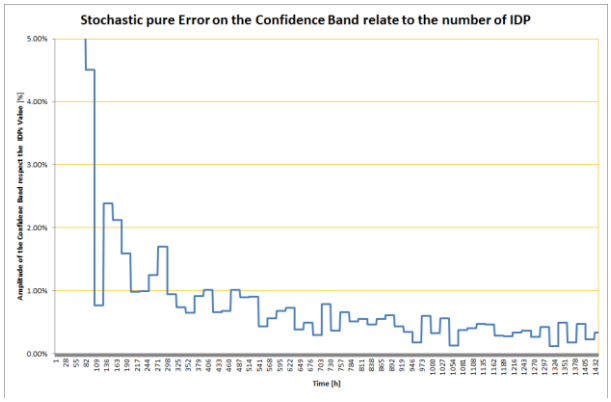

Figure 6: Experimental Error

3.9.3. MEL/MIL 3: Helo

The theatre logistic picture suffered lack of critical information about the logistic situation, sustainability and availability of key equipment:

- Joint Force Logistic Component Headquarters must coordinate a range of logistic support activities to support helo component (UH60 Helicopters)
- Lack of sustainability and availability of key equipment impact scheduled mission

3.9.4. MEL/MIL 3: Evacuation

Local situation is volatile, unstable and likely to deteriorate rapidly:

- Must be able to achieve crowd control without jeopardizing the logistic support and make it easier to carry out the operation,
- A back-and-forth organization reducing the operation's logistical constraints is necessary to plan helicopter rotations in the space of 1 day.

4. SIMULATION AND VV&A

This paper introduces a simulation solution and related scenario. In facts, the formal and static Verification and Validation of the Models has been conducted with Subject Matter Experts (SME) applying different techniques (e.g. face validation, flow charts). The use of DIES IRAE Simulation allowed to present dynamic results and graphics to the SME to proceed in the validation of the conceptual models and experimental results. The authors are currently implementing the MEL/MIL and preliminary experimental results have been carried out in order to support the VV&A based on Design of Experiments (Montgomery 2008). In figure 6 it is proposed the analysis of the experimental error due to the pure influence of stochastic component (Longo et al. 2008). The graph proposes the amplitude of the confidence band respect the number of the IDPs.

CONCLUSIONS

The paper proposes architecture and approach for modeling disaster relief and humanitarian missions in complex environments. The MS2G-based approach has been demonstrated and validated with SME.

The HLA architecture guarantees maximum potential in terms of interoperability with other simulation models. Currently a specific Scenario, addressing South Sudan crisis, is under experimentation. The use of IA-CGF ensures a valid representation of the population behavior and human factors as well as to automate the mission, accordingly to the plan. The stochastic simulation performs risk analysis and evaluation of alternative Courses of Actions (COA). The preliminary experimental results confirm the potential of this approach to support planners and decision makers. The author are working on extending the DIES IRAE Simulation to be effectively applied to emerging crisis situations.

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