UNIVERSITÀ DEGLI STUDI DI GENOVA

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DIME

**Dipartimento di Ingegneria Meccanica, Energetica,
Gestionale e dei Trasporti**

PhD THESIS
IN
MATHEMATICAL ENGINEERING AND SIMULATION
Simulation applied to military sector - tactic and strategic

MODELLING & SIMULATION HYBRID WARFARE
Researches, Models and Tools for Hybrid Warfare and Population Simulation

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TESI DI DOTTORATO
IN
INGEGNERIA MATEMATICA E SIMULAZIONE
Simulazione applicata al settore militare - tattico e strategico

SIMULAZIONE E MODELLAZIONE DELLA GUERRA IBRIDA

Ricerche, modelli e strumenti per la guerra ibrida e la simulazione della popolazione

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The study itself, made in fulfilment of a PhD in Mathematical Engineering and Simulation, it is scientific with regard to the followed methodology, with no intentions or purposes other than provide a rigorous inquiry into the subject of Hybrid Warfare and Human Behaviour Modelling, not contaminated with value judgments, pre-concepts or beliefs of any kind. I hope I have won this struggle.

MODELLING & SIMULATION HYBRID WARFARE
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Abstract

The present work has been inspired by the candidate's membership and active commitment inside the NATO Modelling & Simulation Centre of Excellence (from 2011 to 2018), thus participating at different national and international working groups, workshops, conferences and courses, until current days.
In particular, the candidate acted inside:

1. **MSG 139 "NATO M&S User's Risk Methodology "Task Group**: the probability that inappropriate application of M&S results for the specific intended use will produce unacceptable consequences to the decision maker, had driven NATO to create a Modelling & Simulation Task Group, in order to optimize the use of V&V resources and minimize risks associated with the application of M&S during the development of systems. The Final Report has been submitted to NATO in March 2018;

2. **SIMCJOH Simulation of Multi Coalition Joint Operations involving Human Modelling project:** participation, as Subject Matter Expert, at the development of the conceptual model and VV&A process for SIMCJOH simulator. SIMCJOH (Simulation of Multi Coalition Joint Operations Involving Human Modelling) is a MS2G (Modelling & Interoperable Simulation and Serious Game) project for Strategic Decision Making, designed as a HLA interoperable immersive framework for the Commander and his staff within time-critical decision making over Joint and Multi Coalitions scenarios, considering a strong impact of human factors. SIMCJOH was extensively tested, verified and validated and finally employed by the author at NATO Modelling and Simulation Centre of Excellence during the M&S Basic Course, as "demonstrator" of Human Behaviour Modelling;

3. **NATO Exploratory Team n.43 on Hybrid Warfare (NATO ET 43):** a working group on Hybrid Warfare Modelling and Simulation, tasked in early 2016 to investigate the dynamics of hybrid warfare environments, analyse the requirements, survey the existing capabilities, develop a conceptual model and finally recommend a follow on in order to properly address the shortfalls identified.

In particular, the subject of the "Hybrid Warfare" sparkled the current research. As such, all the previous activities were put into a logic order by their contribution to the framework of the Hybrid Warfare Modelling and Simulation.
The Hybrid Warfare phenomena has been framed by the work of Professor Agostino Bruzzone (University of Genoa) and Professor Erdal Cayirci (University of Stavanger), and thanks to their efforts in June 2016 the NATO Exploratory Team n.43 was approved by NATO Modelling & Simulation Group (a panel of the NATO Science & Technology Organization) and established with the participation as well of Doctor Armando Geller and Lieutenant Colonel Paolo Di Bella. The author brought his personal contribution within the ET43 by introducing insights coming from the lecture of "Fight by the minutes: Time and the Art of War (1994)", written by Lieutenant Colonel US Army (Rtd.) Robert Leonhard. In such work, Leonhard extensively developed the concept that "Time", rather than geometry of the battlefield and/or firepower, is the critical factor to tackle in military operations and by extension in the Hybrid Warfare domain. The critical reflection about the time - both in its quantitative and qualitative dimension - in a hybrid confrontation it is addressed and studied inside SIMCJOH, a software built around challenges that imposes literally to "Fight by the minutes", echoing the concept expressed in the eponymous work.
Furthermore, the author, capitalizing on his personal experience as Officer deployed in several missions abroad in Iraq and Afghanistan, integrated this analysis with time management in Low Intensity Conflict (LIC), Train Advice Assist (TAA) and Security Force Assistance (SFA) mission. In this contest, the mass of the military apparatus appears to asymptotically decelerate into an endless commitment.
Moreover, Hybrid Warfare – which, we will see, by definition and purpose aims to keep the military commitment of both aggressor and defender at the lowest level- can gain enormous profit by employing a wide variety of non-military tools, turning

them into a weapon, as in the case of mass migrations, as it is examined in the “Dies Irae” simulation architecture. Currently, since migration is a very sensitive and controversial issue among the public opinions of many European countries, cynically leveraging on a humanitarian emergency caused by an exogenous, inducted migration, could result in a high level of political and social destabilization, which indeed favours the concurrent actions carried on by other hybrid tools. Other kind of disruption however, are already available in the arsenal of Hybrid Warfare, such cyber threats, information campaigns lead by troll factories for the diffusion of fake/altered news, etc. From this perspective the author examines how the TREX (Threat network simulation for REactive eXperience) simulator is able to offer insights about a hybrid scenario characterized by an intense level of social disruption, brought by cyber-attacks and systemic faking of news. Furthermore, the rising discipline of “Strategic Engineering”, as envisaged by Professor Agostino Bruzzone, when matched with the operational requirements to fulfil in order to counter Hybrid Threats, it brings another innovative, as much as powerful tool, into the professional luggage of the military and the civilian employed in Defence and Homeland security sectors.

This thesis is then structured as follows: chapter 1 describes the theoretical framework developed in order to understand and properly address the concerns posed by Hybrid Threats, in accordance with the Modelling and Simulation (M&S) established foundations and the work of ET 43; chapter 2, with the use of M&S tools and techniques, concrete hybrid scenarios are explored in the contest of a Hybrid Conflict/Military Operation Other Than War (CAPRICORN simulator), with the challenges posed by an exogenous, massive phenomena of mass migration pressing the gates of Europe (examined though the lens of a proposed simulation architecture named “Dies Irae”), and by terrorist attacks coupled with a campaign of truth defacing (T-REX simulator). Then in chapter 3, with the support of M2SG technology and in particular the SIMCJOH simulator, the time concern will be addressed within the frame of a tactical situation, however capable to escalate into a serious strategic blunder because of mismanagement of time and human factors. The results from the reiteration of SIMCJOH scenarios will be displayed with insights.

Finally, in the last chapter, the conclusions and way ahead are drawn.

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GLOSSARY & ACRONYMS

ACLED: Armed Conflict Location & Event Data Project

AFOSR: Air Force Office of Scientific Research

ABMS: Agent-Based Modelling and Simulation

ABSS: Agent-Based Social Simulation

ACT: Allied Command Transformation (NATO)

AJP: Allied Joint Publication (NATO)

AMSP (NATO): Allied Modelling & Simulation Publication

ANA: Afghan National Army

ANOVA: Analysis of Variance

ANP: Afghan National Police

AOP: Aspect Oriented Programming

C2: Command and Control

C2IS: Command and Control Information

C4I: Command, Control, Communications, Computer & Intelligence

CAPRICORN: CIMIC And Planning Research In Complex Operational Realistic Network

CAVE: Cave Automatic Virtual Environment

CAX: Computer Assisted eXercise

C-BML: Coalition Battle Management Language

CBRN: Chemical, Biological, Radiological e Nuclear

CIA: Central Intelligence Agency

CIMIC: Civil Military Cooperation (NATO)

CMA: Civil Military Affairs (US Army)

CLARION: Combined Land Air Representation of Integrated Operations

CLD: Causal Loop Diagram

CoA: Course of Action

CoE: Centre of Excellence

COIN: Counter Insurgency

CONOPS: Concept of Operations

COP: Common Operating Picture

DARPA: Defence Advanced Research Projects Agency

DBN: Dynamic Bayesian Network

DBNL: Distributed Networked Battle Labs

DESA: Department of Economic and Social Affairs (United Nations)

DHSS: Defence and Homeland Security Simulation

DIS: Distributed Interactive Simulation

DIES IRAE: Disasters, Incidents and Emergencies Simulation Interoperable Relief Advanced Evaluator

DIMEFIL: Diplomatic/Political, Information, Military, Economic, Financial, Intelligence, Legal

DIT: Department of Technological Innovations

DON: Distributed Observer Network

DOE: Design of Experiment

DoD: Department of Defence (USA)

DVx2: Distributed Virtual eXperience and eXercise

ELINT: Electronic signals Intelligence

ET: Exploratory Team

EU: European Union

EW: Electronic Warfare

FAO: Food and Agriculture Organization

FOM: Federation Object Model

GESI: GEfechts-SImulation System

GIROA: Government of Islamic Republic of Afghanistan

GM V&V: Generic Methodology for Verification and Validation

GO: Governmental Organization

GOTS: Government Off-The-Shelf

GUI: Graphic User Interface

HABITAT: Harbour Traffic Optimization System

HADR: Humanitarian Assistance and Disaster Relief operations

HBM: Human Behaviour Modelling

HSCBM: Human Social Culture Behaviour Modelling.

HC: Hybrid Conflict

HLA: High Level Architecture

HT: Hybrid Threat

HTL: Human in The Loop

HTN: Hierarchical Task Network

HUMINT: Human Intelligence

HW: Hybrid Warfare

IA: Intelligent Agent

IA&O: Influence Activities and Outreach

IA-CGF: Intelligent Agent - Computer Generated Forces

IA-CGF NFC: Intelligent Agent Computer Generated Forces Non-Conventional Framework

IAW: In Accordance With

IC: International Community

ICT: Information and Communications Technology

IDPs: Internally Displaced Persons

IED: Improvised Explosive Device

IOM: International Organization for Migration

IoT: Internet of Thinghs

ISAF: International Security Assistance Force

ISTAR: Intelligence, Surveillance, Target Acquisition, and Reconnaissance

ISIL/ISIS: Islamic State in Iraq and Syria/Levant

ISIL-K: Islamic State of Iraq and Levant - Korasan province

IT²EC: International Training Technology Exhibition & Conference

I/ITSEC: Inter-service/Industry Training, Simulation, and Education Conference

IW: Irregular Warfare

JESSI: Joint Environment for Serious Games, Simulation and Interoperability

JISR: Joint Intelligence, Surveillance and Reconnaissance

LIC: Low Intensity Conflicts

LVC: Live Virtual Constructive

MEL/MIL: Main Events List/Main Incidents List

M & S: Modelling & Simulation

MSC-LES: Modelling & Simulation Centre - Laboratory of Enterprise Solutions

MSCO: (US) Modelling and Simulation Coordination Office

MoM: Measures of Merits

MOOTW: Military Operations Other Than War

M&S COE: NATO Modelling and Simulation Centre of Excellence

MS2G: Modelling, interoperable Simulation and Serious Game

MSG: (NATO) Modelling and Simulation Group

MSHE: Modelling and Simulation of the Hybrid Environments

MURM: Modelling & simulation User Risk Methodology

NAC: North Atlantic Council

NASA: National Aeronautics and Space Administration

NATO: North Atlantic Treaty Organization

NCF: Non Conventional Framework

NDPP: NATO Defence Planning Process

NEC: Network Enabled Capabilities

NETN FOM: NATO Education and Training Network FOM

NGO: Non- Governmental Organization

NLC: Non-Lethal Capabilities

N2M2C2: NATO Net-enabled Capability (NEC) Command and Control (C2) Maturity Model

OEF: Operation Enduring Freedom

OIF: Operation Iraqi Freedom

OMT: Object Model Template

ONR: Office of Naval Research

OOP: Object Oriented Programming

OPNET: Optimum Network Simulator

OSINT: Open Source Intelligence

PKO: Peace Keeping Operation

PLA: People’s Liberation Army (China)

PMF: Performance Moderator Function

PRB: Pay Research Bureau

PRC: People's Republic of China

PSO: Peace Supporting Operation

PMSEII-PT: Political, Military, Economic, Social, Infrastructure, Information – Physical Environment & Time

PSYOPS: Psychological Operations

R&D: Research and Development

RPG: Role Playing Game

RTI: Run-Time Infrastructure

RSM: Resolute Support Mission

SASO: Stability and Support Operations

SOFA: Status Of Force Arrangements

SSTRO: Stability, Support, Transition, and Reconstruction Operations

SATCOM: Satellite Communication

SEE: Simulation Exploration Experience

SFA: Security Force Assistance

SIMCJOH: Simulation of Multi Coalition Joint Operations involving Human modelling

SIMCJOH VIC: Simulation of Multi Coalition Joint Operations involving Human modelling Virtual Interoperable Commander

SIMCJOH VIS: Simulation of Multi Coalition Joint Operations involving Human modelling Virtual Interoperable Simulator

SISO: Simulation Interoperability Standards Organization

SISO RPR FOM: SISO Real-time Platform Reference Federation Object Model

SME: Subject Matter Experts

SOM: Simulation Object Model

SPIDER: Simulation Practical Immersive Dynamic Environment for Reengineering

STO (NATO): Science and Technology Organization

STRATCOM: Strategic Communication

TAA: Train, Advice, Assist

T-REX: Threat network simulation for REactive eXperience

UAV: Unmanned Aerial Vehicles

UGV: Unmanned Ground Vehicles

UN: United Nations

UNTSO: Unites Nations Truce Supervision Organization

UNIFIL: United Nation Interim Force In Lebanon (UN)

UNFLIE: United Nation Force for Large Improvement of Eblanon (fictional)

UNICAL: University of Calabria

UNIGE: University of Genoa

UUV: Unmanned Underwater Vehicles

V & V: Verification and Validation

VV&A: Verification, Validation & Accreditation

1. Introduction: Modelling and Simulation for Hybrid Environment (MSHE)

The objective of the present introduction is to understand the description of hybrid environments, to identify the M&S requirements with regard to hybrid threats, and finally point out M&S shortfalls and ways for addressing/mitigate them. What follows is an extract of the work carried out by the NATO Exploratory Team 43 between 2016 and 2017, and scientific papers co-presented by the Author at 2018 WAMS workshop, framed within the applicable and relevant M&S foundations. In particular, it is introduced an overview of Agent Based Modelling (ABM) in the DIMEFIL/PMESII domains, with a survey of the current M&S tools available. Finally, we will present two other perspectives which address the issue of Hybrid threats, and in conclusion, we will compare those with the findings of NATO ET 43.

1.1 Hybrid Warfare: Seed and Evolution

Hybrid derives from Latin *hibrida*, meaning the offspring of two creatures, which is indeed an appropriate term to describe such phenomena. One of the first researcher who introduced the concept of Hybrid Warfare was Lieutenant Colonel US Army (Rtd) Frank G. Hoffman, who described it as the “convergence of the physical and the psychological, the kinetic and non-kinetic, and combatants and non-combatants, of states and non-states actors, and of the capabilities they are armed with”. Hybridity, more broadly, means complexity and multi-dimensionality (Hoffman, 2009).

Adopting this perspective, it is possible to track back the genesis of the Hybrid Warfare to the work of two PLA Chinese Colonels (Liang, Q. & Xiangsui, W.), which in 1999 wrote a book called “Unrestricted Warfare”. They argued that Warfare in the modern world will no longer be defined just by military means — or even involve the military at all (*sic!*); instead, society is the battlefield, and so wars would inevitably encompass attacks on all elements of society without limits. Indeed, their thesis was quite revolutionary for the ‘90s, characterized by the post-Cold War posture and the highly (successfully) kinetic military operations named Desert Shield (1990) and Desert Storm (1991). We may say now, after twenty years, that they have been the Precursors/Prophets of Hybrid Conflict; this because indeed nowadays war "is using all means, including armed force or non-armed force, military and non-military, and lethal and nonlethal means to compel the enemy to accept one's interests" (Liang & Xiangsui,1999). Additionally, there isn't a clear distinction between soldiers and civilians, since the fight is taking place virtually everywhere; the new battlefields could include environmental warfare, financial warfare, trade warfare, cultural warfare, and legal warfare, to name just a few (Barno & Bensahel, 2016).

The opera of Liang & Xiangsui foreshadowed the evolution of geopolitics in the 21st century, that has revealed the extent to which conflicts have been influenced by non-linear actions across what has become known as the Diplomatic/Political, Information, Military, Economic, Financial, Intelligence, Legal (DIMEFIL) spectrum.

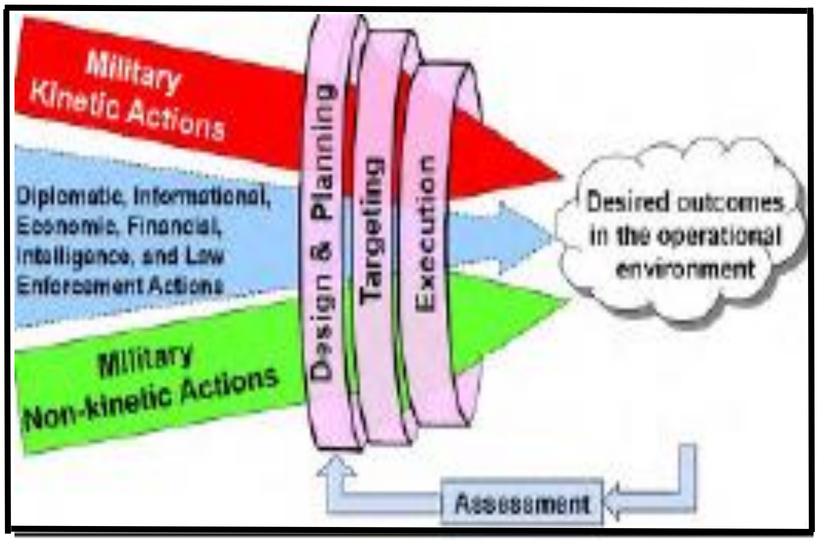


Fig. 1 – Sinergy of kinetic, non-kinetic and DIMEFIL (Hoffman, 2009)

A number of state and non-state actors, even individuals (Wittes & Blum, 2015), have sought to undertake activities coordinated across the DIMEFIL spectrum that challenge the rules of the international order, in order to achieve their political goals.

This is what has become known as Hybrid Warfare (Cayirci, Bruzzone et al. 2016). Hybrid Warfare is underpinned by comprehensive strategies based on a broad complex, adaptive and often highly integrated combination of conventional and unconventional means, overt and covert activities, by military, paramilitary, irregular and civilian actors, which are targeted to achieve (geo)political and strategic objectives (fact box 1- Cayirci, Bruzzone, Di Bella, Geller, 2016).

FACT BOX 1, HYBRID WARFARE IS:

- *HIGHLY INTEGRATED (SYNCHRONIZED)*
    - *A COMBINATION OF CONVENTIONAL AND UNCONVENTIONAL MEANS*
- *OVERT AND COVERT ACTIVITIES*
- *MILITARY, PARAMILITARY, IRREGULAR AND CIVILIAN ACTORS*
- *DIRECTED AT AN ADVERSARY'S VULNERABILITIES*
- *COMPLICATING DECISION MAKING*
- *ACROSS THE FULL DIMEFIL SPECTRUM*
- *CREATING AMBIGUITY AND DENIAL*
- *BOTH STATE AND NON-STATE ACTOR*

They are directed at an adversary's vulnerabilities, focused on complicating decision making and conducted across the full DIMEFIL spectrum in order to create ambiguity and denial. The objective of the owner of the Hybrid Strategy is to impose, over the targeted state, the acceptance of a resulting political situation. Hybrid Strategies can be applied by both state and non-state actors, through different models of engagement, which may vary significantly in sophistication and complexity, with the possibility of maintaining economic and diplomatic relations. For such reason Adversaries employing hybrid strategies will seek to remain ambiguous, either by claiming pursuit of legitimate goals or by keeping their activities below a "threshold" and so avoiding a coordinated response from the International Community (UN Chart, NATO Article 5).

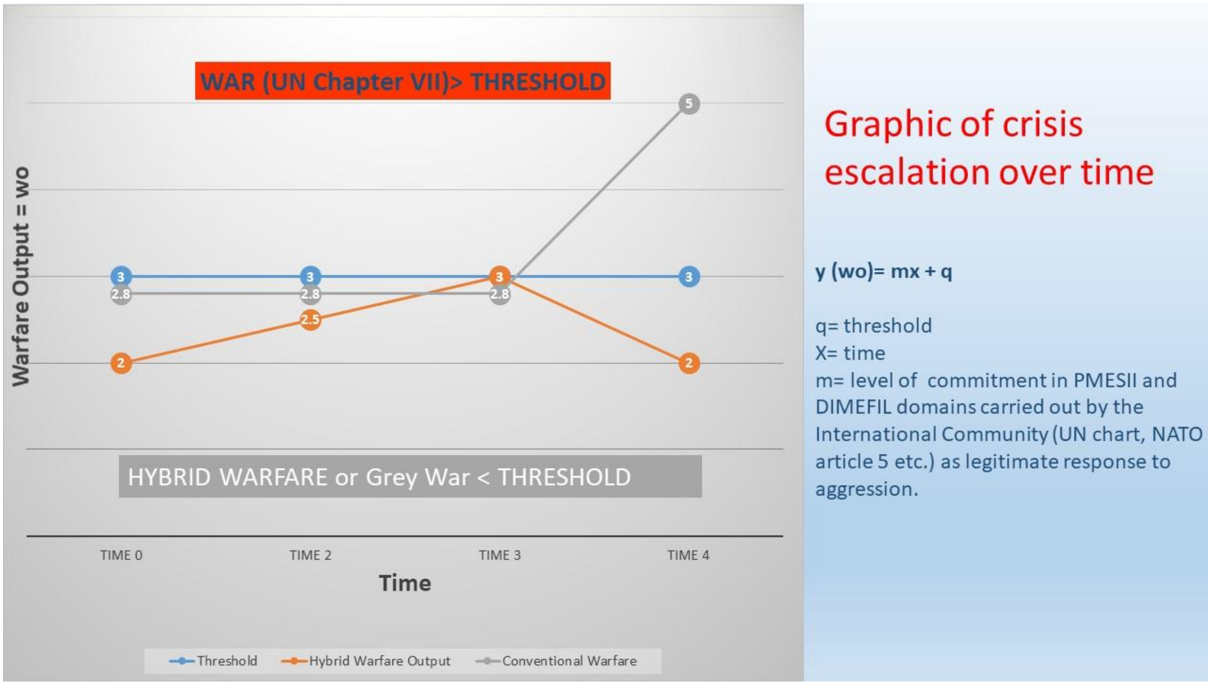


Fig.2 - Graphic of crisis escalation over time

In order to avoid the response of the International Community, it is of capital importance to avoid direct military confrontation if not necessary, even though the use of limited (in size of force over time) overt military actions as part of a hybrid strategy cannot be discounted (fact box 2 - Cayirci, Bruzzone, Di Bella, Geller, 2016).

FACT BOX 2: HYBRID WARFARE IS:

- *COMBINED, POLITICAL, CIVIL AND MILITARY INSTRUMENTS.*
- *POLITICAL AIMS ACHIEVED THROUGH CONVENTIONAL/REGULAR, SUBVERSIVE/IRREGULAR, CRIMINAL/CORRUPT ACTIONS.*
- *INCREASED VULNERABILITIES THROUGH GLOBALIZATION EMPHASIZED BY TECHNOLOGICAL ADVANCES.*
- *FALL SHORT OF DIRECT MILITARY CONFLICT.*
- *COMPLEX PROPAGANDA AND MISINFORMATION CAMPAIGNS.*
- *TARGETED AND COORDINATED POLITICAL AND ECONOMIC PRESSURE.*
- *COMPLICATING, DELAYING AND IMPEDING TIMELY DECISION MAKING.*
- *BOTH STATE AND NON-STATE ACTOR*
- *INTRODUCED AT THE STRATEGIC LEVEL*
- *NO TWO HYBRID STRATEGIES WILL BE THE SAME.*

The use of hybrid strategies in conflict are not new, but what is new for NATO is the way a wide range of political, civil and military instruments are combined and coherently applied, aiming at particular vulnerabilities of targeted nations and international organizations in order to achieve strategic objectives.

From this perspective, Hybrid Warfare could be seen as the "black" counterpart of NATO Comprehensive Approach (Cayirci, Bruzzone et all, 2016); in facts "lessons learned from NATO operations show that addressing crisis situations calls for a comprehensive approach combining political, civilian and military instruments. Building on its unique capabilities and operational experience, including expertise in civilian-military interaction, NATO can contribute to the efforts of the international community for maintaining peace, security and stability, in full coordination with other actors. Military means, although essential, are not enough on their own to meet the many complex challenges to our security. The effective implementation of a comprehensive approach to crisis situations requires nations, international organisations and non-governmental organisations to contribute in a concerted effort" (https://www.nato.int/cps/en/natolive/topics_51633.htm).

However, common to the state and non-state actors is the simultaneous, opportunistic, synergistic and sophisticated combination of conventional/regular, subversive/irregular and criminal/corrupt actions in designated geographic areas to achieve political aims. Globalization, underpinned by technological advances, particularly in the field of communications, including those in cyber space, has led to increased vulnerabilities in nations and international organizations that can be exploited in a variety of scenarios that fall short of direct military conflict. Increasingly sophisticated cyber-attacks, far reaching complex propaganda and disinformation campaigns, as well as targeted and coordinated political and economic pressure are indicative of modern hybrid warfare scenarios, which represents a challenge to the defence of Allies' populations and territory, that is broader and subtle than just a conventional military threat. Furthermore, hybrid strategies aim at complicating, delaying and impeding timely decision making and undermining the ability of a country or an Alliance as a whole to respond to such a threat swiftly, firmly and effectively. In particular, when modelling the defender in a Hybrid contest, it necessary to remind what is the role in NATO attributed to the North Atlantic Council (NAC); standing at the very core of the functionality of the Alliance as collective body, the NAC is the principal political decision-making instance within NATO, overseeing the political and military process relating to security issues affecting the whole Alliance. As such, its decision must be taken unanimously among members on all issues affecting their peace and security; this can and will be exploited as a vulnerability, especially when the owner of the Hybrid Strategy appear to be a monocratic apparatus.

UN / NATO	ROGUE STATES
PLURALISTIC	AUTHORITARIAN- LIMITED PLURALITY
UNANIMITY	N.A.
PUBLICITY	SECRECY
CAVEATS	VERY FEW
SCRUTINY OF THE PUBLIC OPINION	ABSENT
BOTH ACTORS OF THE HYBRID WARFARE ENVIRONMENT	

Fig 3 - Features of typical pluralistic political body vs a typical authoritarian one

Different elements of hybrid strategies will be combined in different ways, resulting in the fact that no two Hybrid Strategies will be the same (Caircyi, Bruzzone et al. 2016). Each individual element of the Hybrid Threat will not necessarily be illegal or pose a threat in their own right, but their combination could threaten individual Allies or the Alliance. The primary response to hybrid threats or attacks rests foremost with the targeted nation, but the wider international community must also be prepared to play an important role. No single nation, supranational entity or international organization has all the levers needed for a coherent counter to hybrid warfare. Modern technology enables even individuals to wield the destructive power of states, making less relevant many of the traditional concepts around which

Western Democracies laws and political organization for security have evolved. National borders, jurisdictional boundaries, citizenship, and the distinctions between national and international, between act of war and crime, and between state and private action all offer divides less sharp than they used to. Any nation can face attack through channels controlled and operated not only by governments but by private "enterprises" as well, and by means against which governments lack the ability to defend. Strung together, these issues describe the security future with which citizens and governments must now struggle with (Wittes & Blum, 2015). For all the above mentioned reasons, any ambition to model hybrid warfare have to take in account the extreme volatility of the aggressive means brought into action.
Having introduced the concept of Hybrid Warfare, in the next paragraphs we will examine the findings of the Modelling and Simulation of Hybrid Environments (MSHE) task group, with a focus on the human and social behaviour modelling, because most of the related work that can be useful in MSHE is from that field. A survey of the current available modelling & simulation tools will be presented.
However, in order to do that, it necessary to introduce the foundations of such M&S tools, in terms of employing Social Behaviour Models and Agent Based Simulation and their implementation into DIMEFIL modelling process, which is the cornerstone of Hybrid Warfare modelling.

1.2 Rationale to employ Models in Hybrid Warfare

A model is a simplified representation - small scale, less detailed, less complex - of an empirical target, as for example a social structure, system or phenomenon (Gilbert & Troitzsch, 2005). Rather than studying the empirical target directly, because it is impossible or difficult, a model is built that can scale down the target, simplify it to make it more tractable or substitute it with analogical examples (e.g., the hydraulic model of an economic system or the computer model of the mind). Models can perform two fundamentally different representational functions. On the one hand, a model can be a representation of a selected part of the world (the 'target system'). Depending on the nature of the target, such models are either models of phenomena or models of data. On the other hand, a model can represent a theory in the sense that it interprets the laws and axioms of that theory.
There are three basic concepts to take into account when developing a model:

I) Abstraction, which is the degree to which (a model) is simplified to its base form, concept or idea, so that only the important characteristics (based on purpose of model), attributes or behaviors are apparent;

II) Fidelity, which is the degree to which the representation within a model or simulation is similar to a real-world object, feature, or condition in a measurable or perceived manner;

III) Resolution: The degree of detail used to represent aspects of the real world or a specified standard or referent by a model or simulation.

In general, more Abstraction leads to less Fidelity, while Resolution and fidelity are mutually exclusive, so you can have a greater degree of one and not the other; this depends on what you are trying to accomplish. The picture below shows, within the military domain, the Model hierarchy in reference with Abstraction, Fidelity and Resolution.

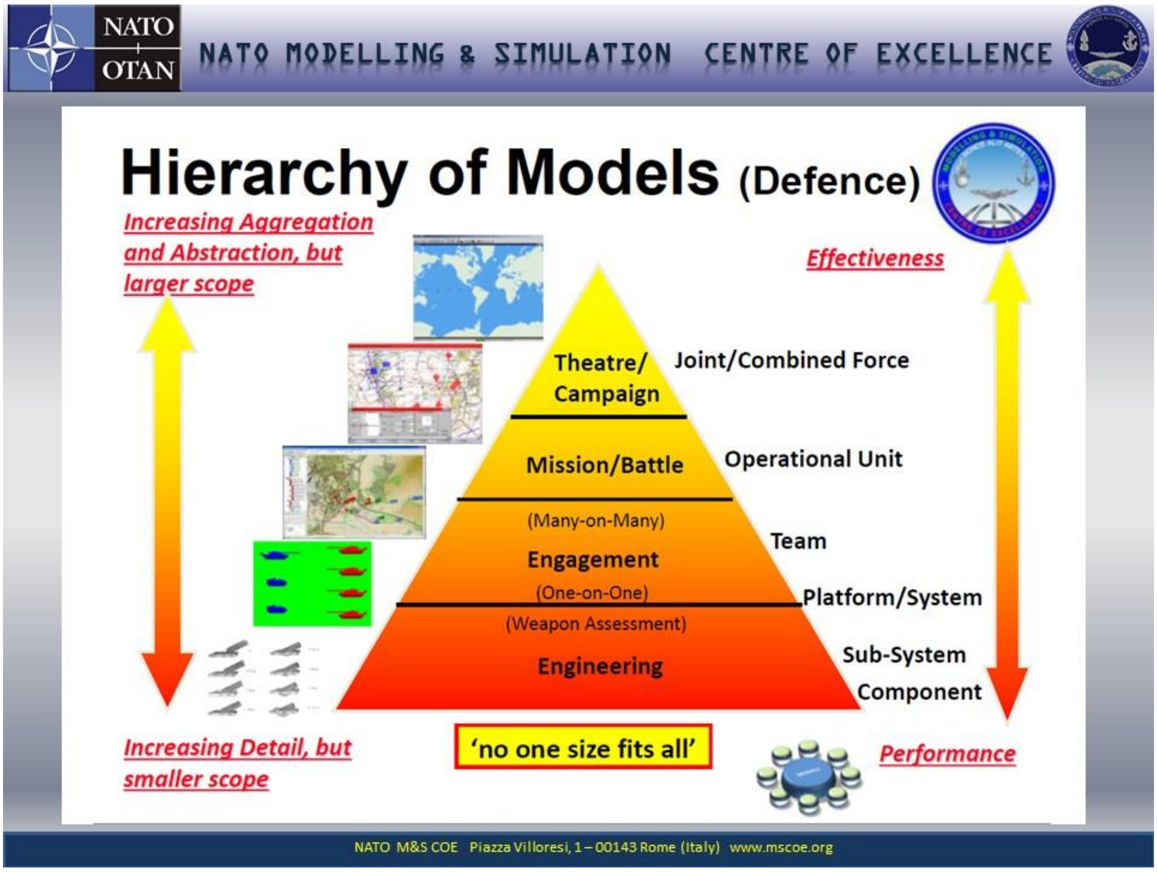


Fig. 4 - Hierarchy of Models, NATO M&S Course, NATO MS COE, 2018.

The model can have a theoretical purpose, for example, understanding macro implications of theoretical assumptions about micro processes, or a more empirical one, for example, drawing intuitions from existing raw data (Hartmann and Frigg 2006). Epstein (2008) reported a detailed list of reasons to build models in social sciences. They are (not in order of importance): [predict], explain, guide data collection, illuminate core dynamics, suggest dynamical analogies, discover new questions, promote a scientific habit of mind, bound (bracket) outcomes to plausible ranges, illuminate core uncertainties, offer crisis options in near-real time, demonstrate trade-offs/suggest efficiencies, challenge the robustness of prevailing theory through perturbations, expose prevailing wisdom as incompatible with available data, train practitioners, discipline the policy dialogues, educate the general public, reveal the apparently simple (complex) to be complex (simple).

For whatever reason, generally, models make reality more understandable in scientific terms, and a significant proportion of research is carried out on them rather than on reality itself (Hartmann and Frigg 2006). They have a learning function, as scientists can learn about the target exactly because they discover features and ascertain facts by manipulating the model. In this case, the model itself becomes the "real" object of research as it and only it can be subjected to peer scrutiny, extension, testing, and comparison. In many respects, such a categorization orients itself along the lines of a scale that has been developed by Axtell and Epstein (1994), in which any model can be placed on levels 0 to 3, depending on performance and analysis:

a) 0 level model is a "caricature";
b) a level 1 model which "is in qualitative agreement with empirical macro-structures";
c) a level 2 model which "produces quantitative agreement with empirical macro-structures";
d) a level 3 model which "exhibits quantitative agreement with empirical micro-structures".

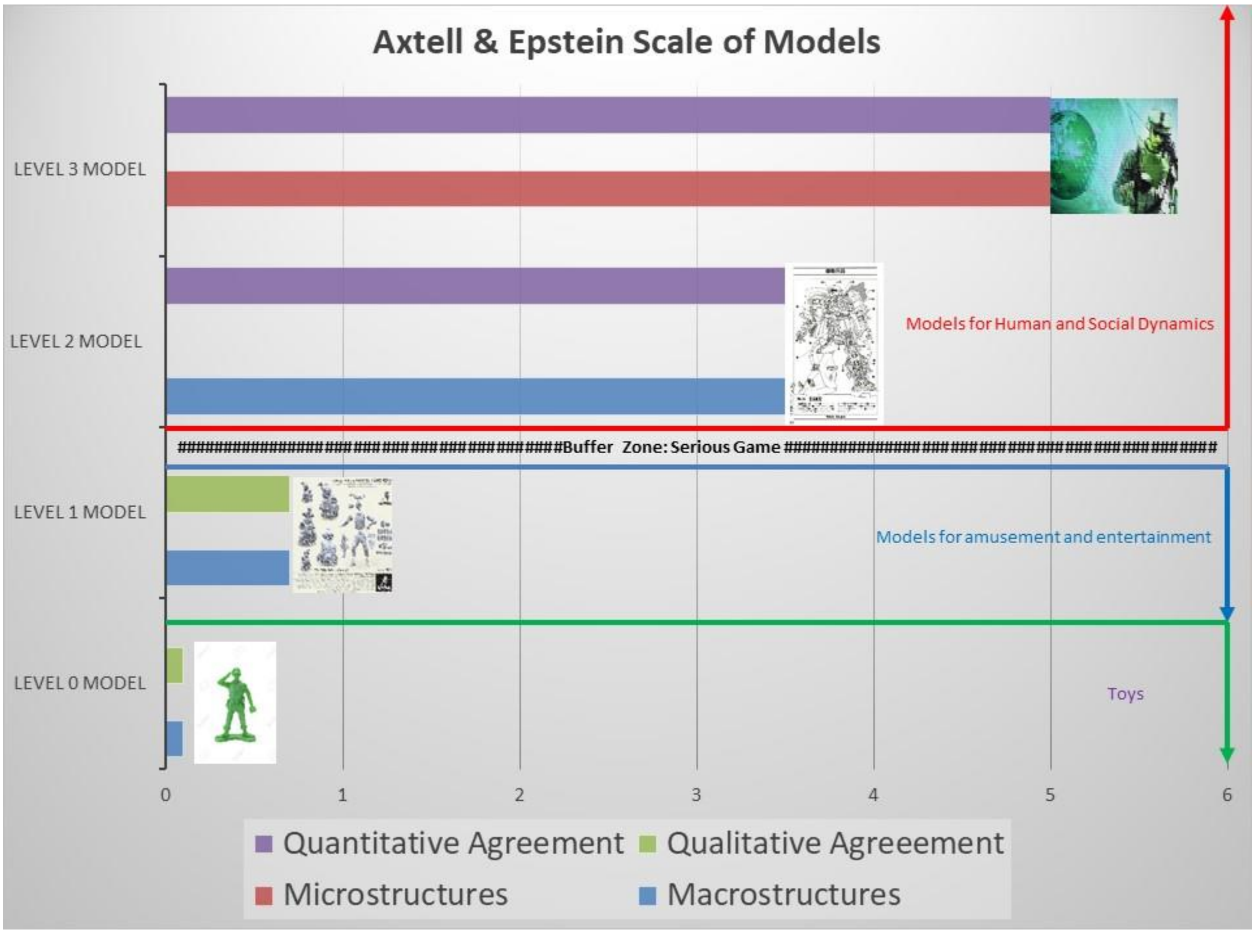


Figure 5 - Axtell & Epstein scale of Model (1994), revisited (Di Bella, 2019).

Models that are devised to support real word decision making or training will have to be located on levels 2 and 3; in other words, models and simulations that are built for the purpose of representing human and social dynamics have to be necessarily located on level 2 or higher; therefore, they need to be empirically driven and based, and validated across multiple scales (Axell & Epstein, 1994).
However, between the "entertainment" and "model for social dynamic", according to the author, there could be a sort of buffer zone, where the so called "Serious Game" are placed. They merge the ludic characteristic with some degrees of "reality", being able to reproduce inside the game mechanics the behaviour of real phenomena; particularly in the case of war-game with historical (the real military units that took part in the engagement), geographical (the battleground reproduced with its features) and mathematical (attrition and loss) accuracy. Their goals are to entertain, yes, but to educate as well.

Among those purposely born for entertainment, worth to mention are rare cases of games which turn into a serious game and more, as the fortunate series of paper game and PC game named "Harpoon". Born in the 80' and computer coded in the 90's, over thirty-plus years witnessed how military professionals used the commercial product in their official jobs: for education and for training, when they used the product to do desktop analysis before engaging in various war games on mainframes (e.g., at the US Naval War College) or with actual forces in the field conducting live simulations (Gilman & Bond 2016). The RAND Corporation used the system to evaluate a Taiwan vs. China engagement (Shlapak, et al. 2000). The bitter irony was the inability of the military establishment to adopt a $50 "game" (Harpoon), even though their multimillion dollar systems only accomplished a fraction of the same functionality (Gilman & Bond, 2016).

Fig.6 - Harpoon 3 Basic Display (Gilman, 2016)

A recently issued game born with the explicit task of "Entertain & Educate" is *Command Modern Air Naval Operations (CMANO),* declared as the global (gaming) simulation of modern warfare at sea, in the air, in space and over land, which comes accompanied by a 323 page's rule book (Matrix Games, 2019).

Fig.7- CMANO opening screen

1.3 Multi-Agent and Agent based Simulations

Agent-Based Models (ABMs) are a means of understanding the mechanisms which are responsible for the macro patterns under scrutiny. The idea is that the macro behaviour of social systems can be better understood bottom-up, rather than beginning with a set of variables and their predefined relations. Here lies the real uniqueness of the ABM approach, compared with other approaches that investigate social patterns through the computer (Castellani & Hafferty, 2009).

ABMs are stochastic simulations that are built around dynamically interacting objects called agents, which usually are all of comparable size and scope (Hartley, 2015). On this regard, human and social dynamics modelling can be only performed by means of employing multi-agent simulation technique (Squazzoni, 2012). In some ABMs the agents are all identical copies of the same object, while in others there are two or more types of agents. The agents have pre-set attributes and behaviours; however, the choice of data inputs can dramatically change the model's purported real-world ideal. For example, the same agents in an ABM can represent soldiers with a mission in one model and a set of mines in the ocean in another model. Generally, ABMs contain some spatial representation, (x, y) or (x, y, z) coordinates, that can be used to model real-world distances. Only multi-agent simulations concomitantly allow for realistically taking into consideration human cognition and behaviour in a social context (Geller, 2016). Many types of agent-based models exist, and differences can be found in empirical foundations, degree and range of validity, and the purpose of agent-based models.

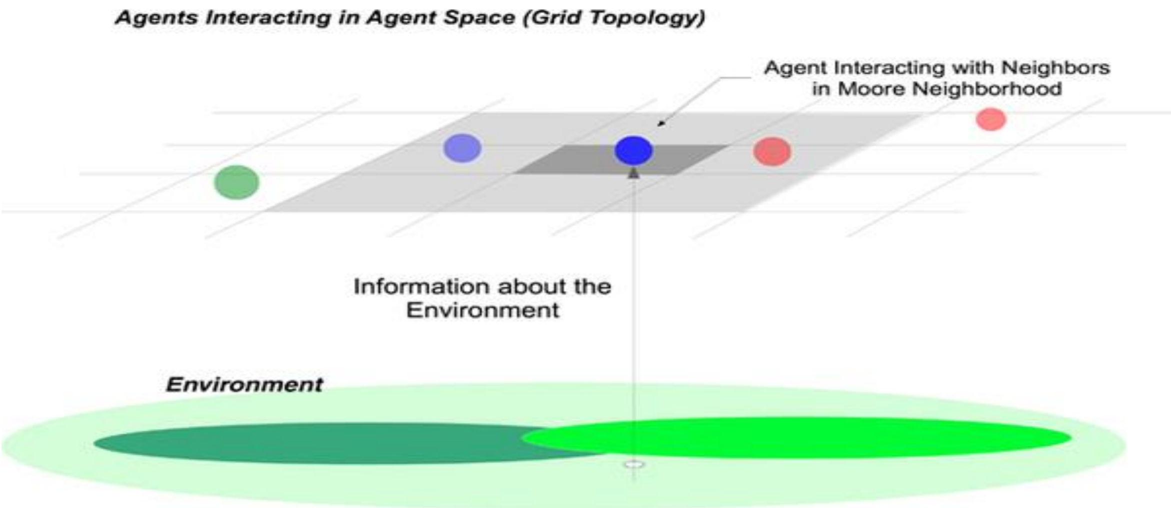


Fig.8 - Agents Interacting in Agent Space (Springer, Tutorial on ABMS)

Agent based modelling focuses on the individual active components of a system. This is in contrast to both the more abstract system dynamics approach, and the process-focused discrete event method. With agent based modelling, active entities, known as agents, must be identified and their behaviour defined; they may be people, vehicles, equipment, or whatever is relevant to the system. When connections among them are established and environmental variables set, the simulations run and so the global dynamics of the system emerge from the interactions of the many individual behaviours (Castellani & Hafferty, 2009).

The simulations that are most commonly referred to as ABMs have simple sets of rules; however, the simulations are dynamic. The rules mesh together during the simulation run and produce often surprising, emergent behaviours. The stochastic nature of the models and the sensitivity to small changes means that thousands to millions of runs are required to understand the range of behaviours, their frequencies, and associations with input data. The outcomes are non-linear, that is, not predictable beyond small time increments. Further, the results from N iterations will likely differ from the results of $N + M$ iterations. The emergence of complex behaviours from simple sets of rules is the principal reason for using ABMs; the best way to understand the complexity of human interactions is to investigate the emergence of complex interactions from simple simulation rules in an ABM (Geller, 2016).

The more complex ABMs incorporate variable behaviours. These ABMs support connected sequences of runs in which the results of previous runs are used to modify the behaviours in subsequent runs. These ABMs are adaptive and can generate the coevolution of the behaviours of one or more groups of agents (sides).

The ABMs of interest here are the models that include attributes such as emotions, opinions, and social grouping valences (Hartley, 2015). These attributes present problems because our understanding of the true relationships among such variables is poor, and so validating the code is difficult. Further, some ABM proponents claim that the primitives that make up the relationships are what should be modelled, and that by observing the emergent behaviour users can make correlations between these and real-world behaviour.

The ideal ABM would be a completely protean, content free model in which any situation in any portion of reality could be modelled simply by changing the data and changing the human meanings attached to the objects and labels of the model

(Hartley, 2015). Thus the dots on the computer screen that the model uses to portray the agents can be thought of as individual soldiers or as floating mines. The rules governing movement toward or away from other agents can be thought of as social rules of liking or disliking or as representing the physical constraints of chains and wave action. On that regard, Multi-agent simulations create simplified versions of social actors, groups or organizations, along with their behaviours and the environments they inhabit; these social actors are called agents, which are autonomous and interact with one another to achieve goals (Bonabeau, 2002).

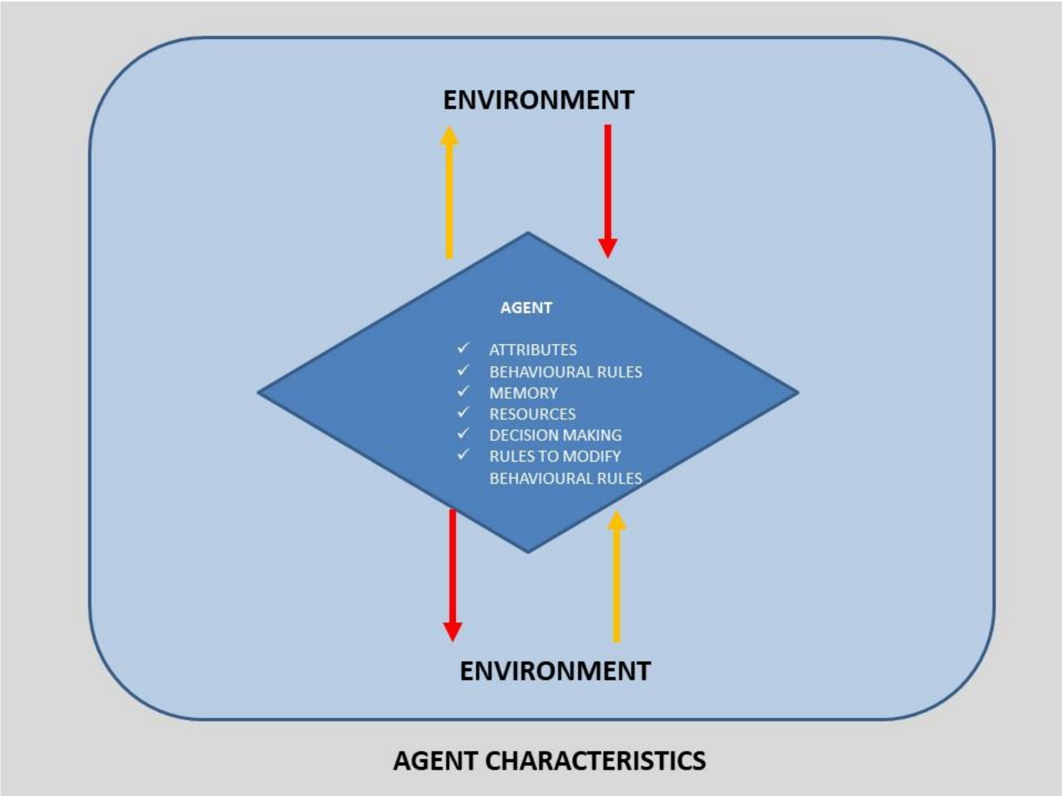


Fig. 9 - Agent characteristics

For instance, in a multi-agent model of a football game, the agents are the players, coaching and support staffs, referees and spectators. Their environment is composed of the stadium and weather. The players have positions, skills, health and physical conditions; the coaches, game's strategies; the referees the same characteristics as the players (plus a hidden amount of bias in assigning penalties). Forward, midfielder and defence players have common and specialized behaviours. The outcomes of these agents' behaviours depend on the initial conditions of the game and how they evolve. For instance, forwards' goal capability depends on their vision, game reading ability, legs strength and accuracy, along with the weather and wind shear. The relationships among these factors are represented as algorithms in the simulation, which represent knowledge gained by observation, field surveys, and statistical data into computer procedures that describe agent behaviour. Algorithms can be more than if-then rules based on empirical data, because agents can have memory and learn. For example, the midfielder can remember how many times he has passed the ball to the forward and seeing how many have been gone through. Since it is difficult to compute outcomes of agents' interaction mathematically, multi-agent models should be simulated by a computer (Wooldridge & Jennings, 1995). That is why multi-agent models are often rendered as simulations.

Specific studies have been focused on using multi-level agents in complex system modelling to derive macro-level group agent behaviours from micro-level agents; moreover, different types of agents have been investigated to reproduce proper human external behaviour as well as human thinking (Takadama et al. 2007; 2008). Indeed, the modelling based on Multi Agents is capable of capturing collective effect in simulations resulting from their interactions (Macal et al. 2010). Furthermore, human behaviour models have been widely used to investigate reaction of populations during emergency situations; multi-agent simulations enjoy richness of narrative and rigor of mathematics, because they use data on actors' perceptions, intentions, actions, and reasoning to inform behaviours. They also account for the physical space and networks of links among social actors (Axtell 2000). Multi-agent simulations serve as virtual labs in which a system can be recreated as a counterfactual to the world where policies, plans, programs and projects are implemented. This property of multi-agent simulations impact assessment and program evaluation because it makes attribution of effects to specific interventions possible. That is why multi-agent simulations are popular tools in designing, analysing and evaluating complex socio natural systems such as combat (Ilachinski 2004), civil wars (Epstein 2002; Latek et al. 2013), environmental management (Matthews et al. 2007), urban planning (Batty 2007), economic development (Geller et al. 2012) and finance (Samanidou et al. 2007; Tesfatsion & Judd, 2006) to name a few.

The simulation of Hybrid Warfare is a very challenging framework as well as the modelling of population and requires sophisticated conceptual model and proper implementation (Alam & Geller 2012). Agent Based Modelling and Simulation, as already outlined, is the most powerful modelling approach and enables many possibilities. Indeed, the use of Object Oriented Programming (OOP), for instance using Java, C++ or C#, is a very powerful approach to develop agent driven simulations of people and population (Signorile, 2004). In facts from this point of view, there are many M&S tools and approach exist that could be used to model and simulate population (Zhang 2016). Among them: Repast (Tatara et al. 2006) which encapsulates both JAVA/C++, ReLogo that adopt AOP (Ozik et al.2013), CORMAS – Common Pool Resource and Multi Agent Systems (Le Page et al. 2000), Ascape (Parker 2001), MASON (Luke et al. 2005), NetLogo Toolkit (Wilensky 1999), Swarm (Minar et al., 1996; Lingnau & Drobnik 1999) and AnyLogic (Borshchev et al. 2002). Therefore, most of them are generalist toolkit and languages that could be used to build up models and requires obviously the severe effort of the model expert to define, implement, characterize and tailor the Hybrid Warfare context, based on skills and expertise as always happen in M&S (McLeod 1982). However, some of the above mentioned simulations have been described (para 1.5) because of their relevance versus MSHE.

1.4. Modelling DIME/PMESII domains for Hybrid Warfare

The exploration of the existing models and simulations relevant to Hybrid Warfare must be pre-empted by an explanation of the conceptual framework where the hybrid interactions take place, which consist in the DIMEFIL power and the related PMESII status (Hillson, 2009; Hartley, 2015; Cayirci, Bruzzone et al. 2016; Balaban & Mielniczek, 2018; Bekkers et al. 2019). The acronym DIMEFIL refers to Diplomatic, Information, Military, Economic, Financial, Intelligence and Law Enforcement level of power of a nation, while PMESII refers to the Political, Military, Economic, Social, Information, and Infrastructure variables that describe the status of a situation (state vector).

Throughout history, governments, groups, organizations (and individuals sometimes) have sought to exert influence over others via a range of policies and actions, in order to achieve a range of objectives. In the current discourse, the components associated with power and influence projection are abstracted into Diplomatic, Informational, Military, Economic, Financial, Intelligence and Law

Enforcement (DIMEFIL) actions, while the resultant impacts are typically characterized as Political, Military, Economic, Social, Informational, and Infrastructural (PMESII) effects. Much more recently, efforts based on social, political, and economic theories have attempted to represent, at least in part, limited DIMEFIL/PMESII scenarios in a systematic manner suitable for automated computer simulation (Hillson, 2009).

Adopting this perspective, it is evident that modern (and past as well) military operations and conflicts cannot be described in purely kinetic effect terms, such as damage and kills (Hartley, 2015). Even more than in the past, current military operations need the capability to understand the human terrain and the various dimension of human behaviour within it (Levis & Elder, 2016). Leonhard (1994) regroup military operations as: Peace (Support) Operations (PO/PSO), Humanitarian Assistance (HA) and Disaster Relief (DR) together HADR, Counter Insurgency (COIN), Counter Terrorism (CT), and (Military) Operations Other Than War (MOOTW); later operations have been called Stability and Support Operations (SASO), and Stability, Support, Transition, and Reconstruction operations (SSTR or SSTRO). In this framework, quantitative measure of the popular perception of security, the level of support for the indigenous government, the economic stability of the country, and other non-strictly and non-military variables are important indicators of success. Some tangible non-kinetic effect variables, such as the state of infrastructure reconstruction, free elections, are important. The technical approaches that have been used to model these operations have generated DIMEFIL, which refers to the levers of power that a nation has to influence the PMESII state. Examples of individual PMESII states include (US Office Secretary of Defence, 2009):

- ❖ Political: structure, process, policy, laws, diplomatic standings, plans, etc.
- ❖ Military: status, ROEs, objectives, physical security status, capability, morale, etc.
- ❖ Economic: policy, production, norms, behaviours, confidence, etc.
- ❖ Social: perception, opinions, attitudes, norms, networks, demographics, etc.
- ❖ Information: sources, content, coverage, quality, availability, etc.
- ❖ Infrastructure: condition, networks, capability, demand, loads, etc.

Each individual state consists of its current value and associated temporal trend (time derivatives). Thus the individual states vary temporally, spatially, and categorically across the groups of actors, the socio-behavioural contexts, interaction protocols, and the physical environment.

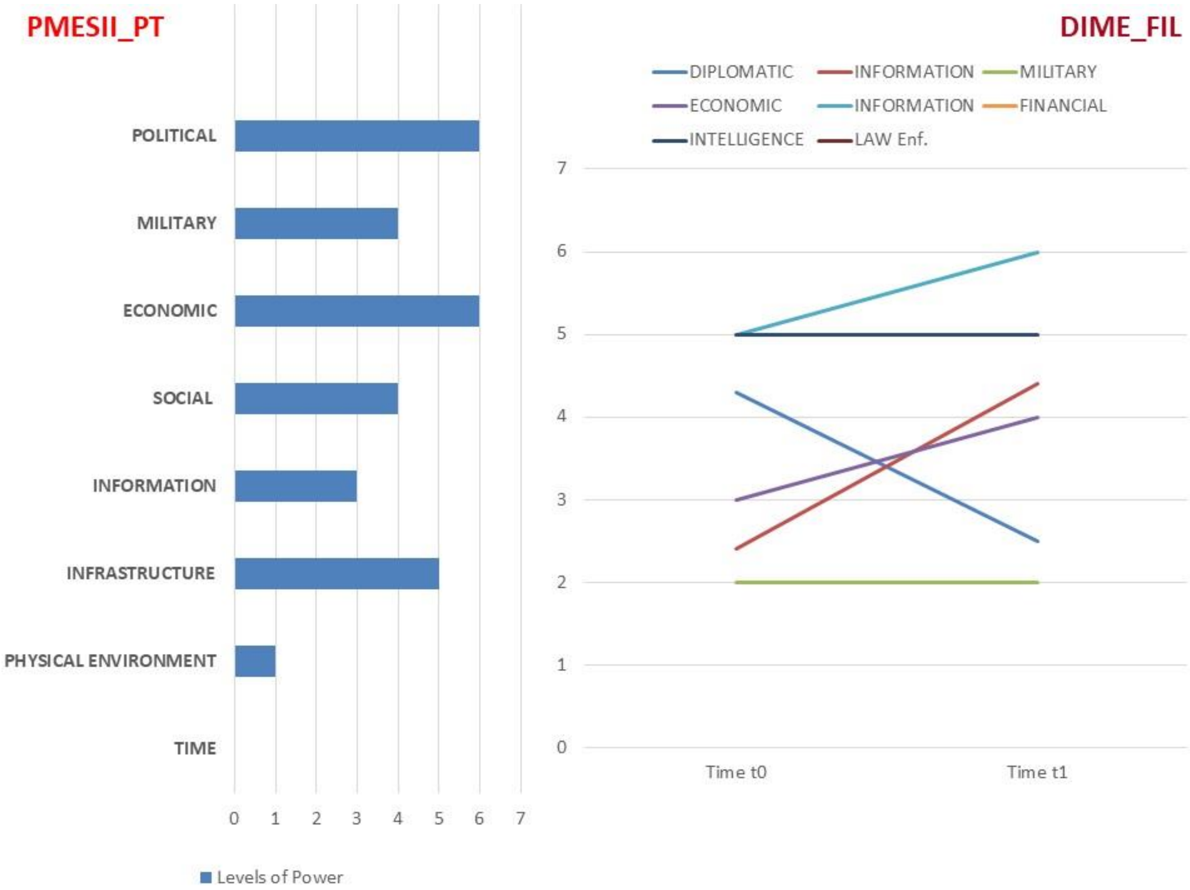


Fig.10 - PMESII_PT state vectors vs DIMEFIL levels of power

The performance of operations that required more than kinetic effects (a polite term for destructive effects through physical means) drove the development of DIMEFIL/PMESII models. Similarly, the development of DIMEFIL/PMESII models is driving a need to understand and apply social science theories. Therefore, we have a new acronym and term, HSCB Modelling, which stands for Human Social Culture Behaviour Modelling. When using the acronym, HSCB, the focus is on the theoretical basis of a model whereas, DIMEFIL/PMESII focuses on the technical details needed to implement a model. When the focus is on the operations being modelled, models may be cited as OOTW, SASO, etc., models; however, it has become clear that most of the operations listed above will require DIMEFIL/PMESII modelling techniques, supported by a firm HSCB basis.

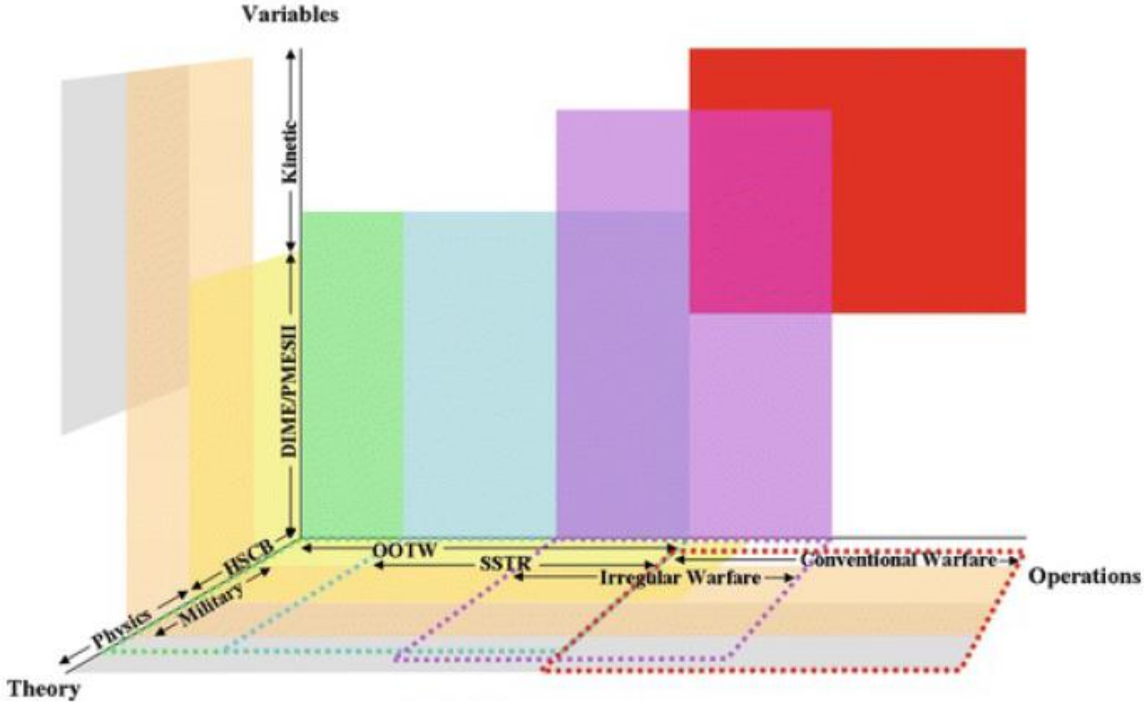


Fig.11 - Categorization of Military Operations (Hartley, 2015)

PMESII models are like other models; they have inputs, logic, and outputs, all mediated by variables; however, there was an historical reluctance of military modellers to use “soft factors” in their simulations, especially in the Military computer combat models of the late 1960s and early 1970s.

Consider figure below in which the PMESII categories have been subdivided. The entire complement of those early military models would be contained just in the Military/Conflict subcategory (green boxed).

Fig. 12 -PMESII categories (Hartley, 2015)

One can understand that there is an (implicit) assumption when looking at the categories of fig. 12: that each of these 27 subcategories is independent of all the others. This is obviously not the case, because some of these subcategories are probably correlated; for example, good health care might not be found where education levels are too low. Thus, there might actually be fewer than 27 independent dimensions. On the other hand, some of the subcategories are probably composites, increasing the actual number of dimensions; on this perspective, the true dimensionality can only be approximated. The dimensionality issue causes problems with understanding the outputs of a PMESII model, even assuming that it is a perfect model. Figure 13 displays an example of a 27-dimensional PMESII snapshot of the state of some geopolitical area. A simulation model would generate a series of such snapshots over its simulated time domain.

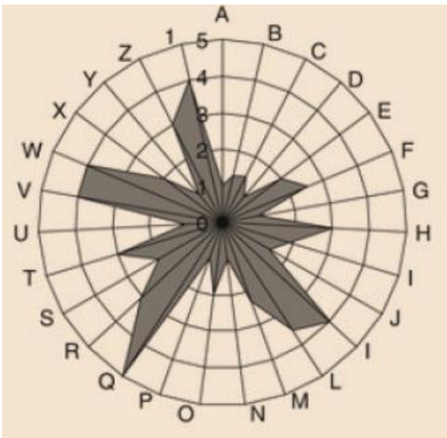


Fig. 13 - PMESII Dimensional radar diagram

A second difference between kinetic models and PMESII models lies in the nature of our understanding of their underlying realities. Kinetic models rely on physics, which at the gross level is well-understood. The non-kinetic parts of PMESII models rely on economics, sociology, psychology, and other very poorly understood sciences. Thus not only should the size of the implicit error intervals for each variable be increased, but also some of the assumed interaction relationships are probably wrong, meaning that is hazardous to compel correlation in a cause-effect scheme with linear dependencies among them (Hartley, 2015).

In particular, PMESII system models are (Allen, 2006):

a) non-linear: the response to multiple inputs it is not the same as the composite of the responses of individual input;
b) non-reversible: don’t always return to the origin, or not along the same path, as in a hysteresis cycle;
c) non-deterministic: future states are uncertain, and the process is stochastic;
d) non-stationary: statistical properties vary with time;
e) non ergodic: an unexpected behaviour can rise because the statistical description of individuals over time are not the same as the statistical description of the whole group at a given time or the whole group over time;
f) non-invertible: initial conditions of the system cannot be inferred from knowledge of the output.

According to Allen (2006), the PMESII modelling should consist of:

I) creation of behaviour paradigms from psychology, sociology, anthropology, political science, military, economics, and modelling them using algorithms and/or agent object simulation;

II) creation of databases, model parameters, and initial conditions for any scenario;

III) actions and effects of real-world users must be translated into definitions that correspond to the model. Finally, the actions can be input as independent variables, the model can be run and the dependent variables/outputs can be observed as effects.

A third important factor is actually common to both types of models, although only recently recognized. During the early times of military computer modelling, all relationships were assumed to be essentially deterministic, although some required stochastic modelling due to inherent measurement errors. Overall, there is every reason to believe that PMESII models and the reality they model are also subject to these complexity and chaos problems (Hartley, 2015).

In modelling PMESII, the below approaches have been identified (Hartley, 2015):

- Segmentation by Agent/Object: the concept is that a few significant persons and groups operate as independent actors, with geographically distributed demographic categories of people operating as opinion repositories. Events (E 1, E 2, …) impact each of the actors/objects (in appropriate ways), with impacts propagating to external countries, including active interveners, and active NGOs. The active interveners and the NGOs post events to the event list, representing their actions, while actors with negative intent are not explicitly pictured.

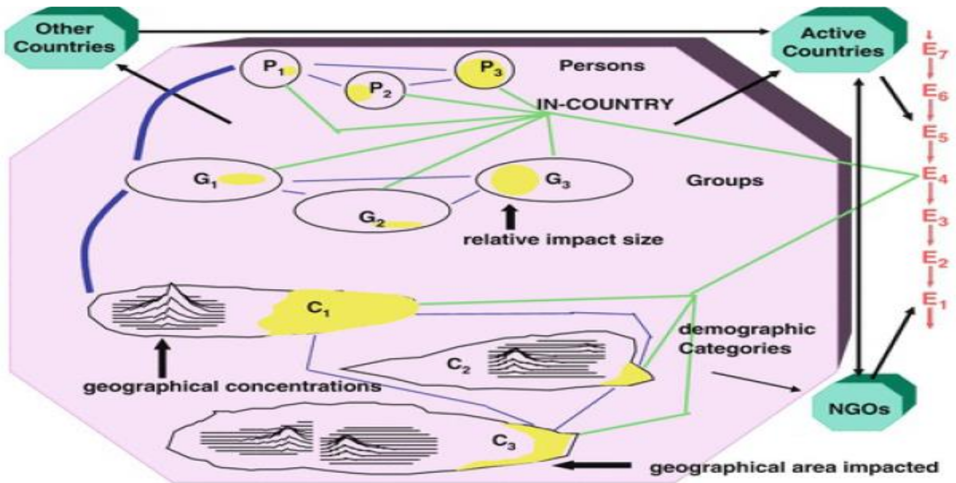


Fig. 14 - PMESII agent objects (Hartley, 2015)

- Segmentation by PMESII Category: it describes the PMESII system in terms of links and nodes within and among the six PMESII categories, as shown in Fig. 16 below. Each category is considered to be a system and must be analysed as such. Further, these systems interact with each other, The nodes in the HQ DA picture are specific physical, functional, or behavioural entities within each system. The nodes can be facilities, forces, people, information, or other types of system components. The links are the connections between the nodes, which can be physical, functional, or behavioural in nature. In addition, the links have a strength-of-connection attribute. Node and link analyses will determine potential "decisive points," which help in identifying the centres of gravity.

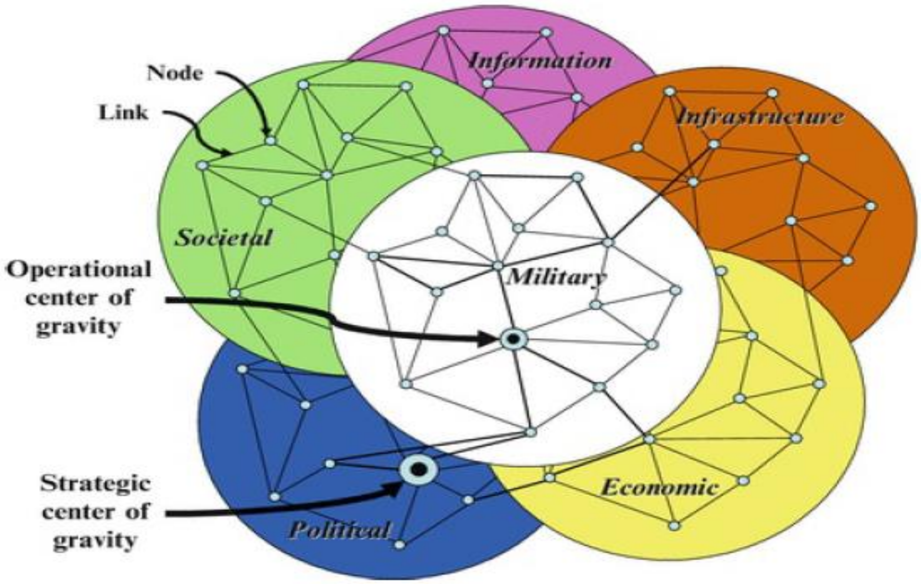


Fig. 15 -View of PMESII System (Hartley, 2015)

- Influence and Causal Networks: The Analysts' Guide for the Interim Semi-Static Stability Model (ISSM) - a model that supports understanding the evolution of a situation (Hartley, 2006) - describes a node and link system that is divided into sectors with connections among the nodes in each sector and between the sectors (Fig. 17 below).

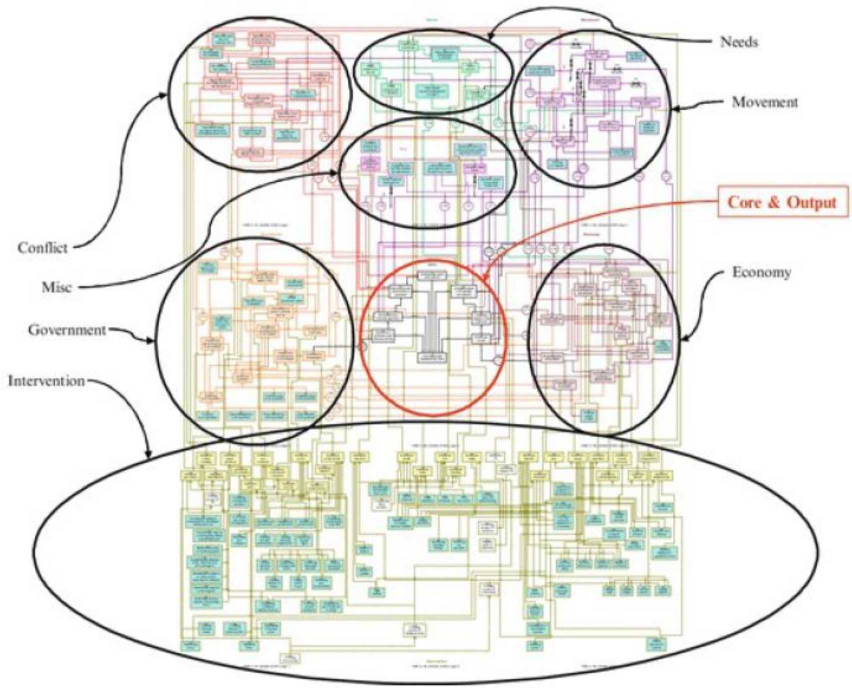


Fig. 16 - Influence and causal networks (Hartley, 2015)

There is visual similarity to the Segmentation concept; however, the nodes and links have different meanings. In the ISSM, the nodes are DIME and PMESII variables and the links are inferential links, some timeless and sometime delayed. There are several levels of variables. While this is a relatively simple model, it still has a large number of variables and requires some decomposition to support human understanding. The input and intermediate variables are divided into six sectors: conflict, economy, government, miscellaneous, movement, and needs. These variables feed into the variables of the final output, which is divided into the core sector and output variable. The relationships among these PMESII variables are shown in the upper two-thirds of the inference-diagram in Figure 17; the lower third of figure consists of the DIME variables, that is, the variables that represent the interventions in the situation being modelled.

The upper portion derives from the findings of “Doing Windows: Non-Traditional Military Responses to Complex Emergencies” (Hayes & Sands, 1997), in which the authors examines how military complex contingency operations can be executed in a way that supports long-term political objectives such as establishment of civil stability and a durable peace.

The Situational Influence Assessment Module (SIAM) was the software (windows fashioned) built upon such requirements in order to plan and train military staff responses to complex emergencies (Figure 18 below).
The networks created in SIAM can be used to identify important issues, actions, or factors that can influence a specific outcome in a given situation. SIAM uses Bayesian probability techniques to assess the relationships among factors, and as such its results are probabilistic, not deterministic, or better not predictive; it is a tool designed for performing "what if" analysis.

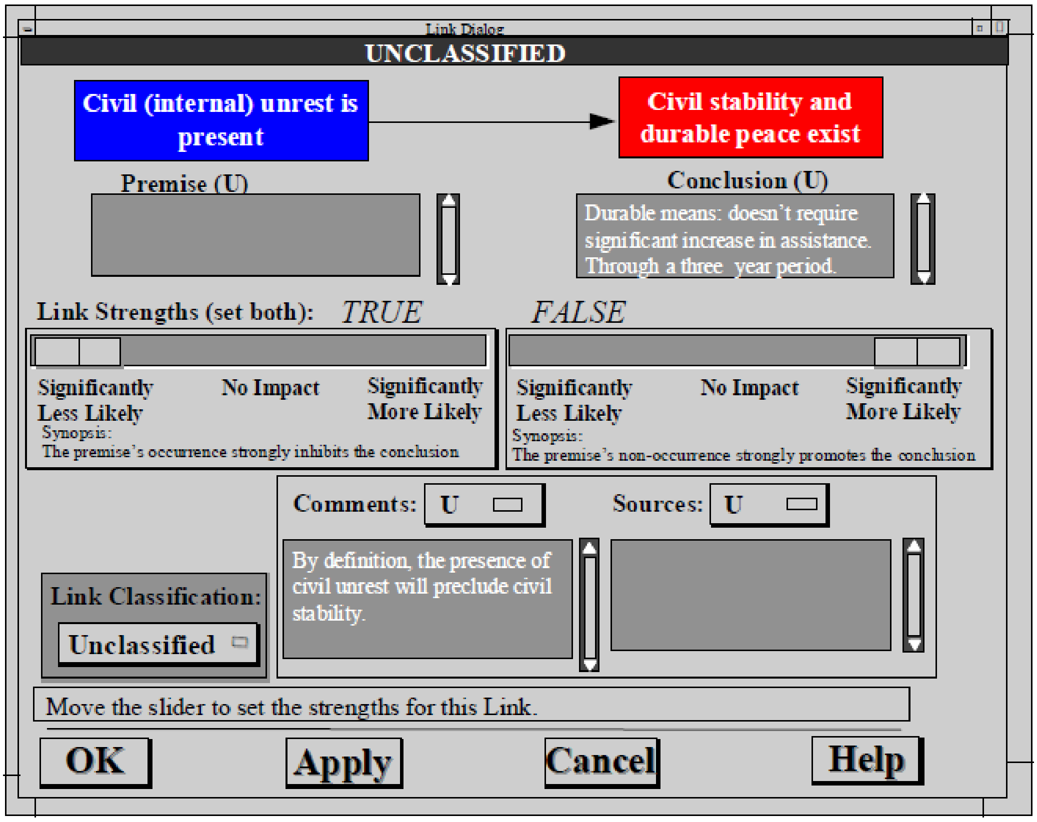


Fig. 17 – SIAM screenshot
http://www.dodccrp.org/files/Hayes_Doing_Windows.pdf

In this contest it is necessary indeed to understand the role of Static Models, Time, and Feedback Loops.
Time flows in the real world and actions cause reactions. These reactions are feedback loops, sometimes acting to damp the original actions (negative feedback) and sometimes adding to the effects of the original actions (positive feedback).

Negative and positive feedback are clocked by time, which affects and drives decisions; population, friendly forces, insurgent – each of them view/perceive time its own way and pursue its objective according to such perception (Di Bella, 2019). Static models are representations of situations at a given instant and thus not capable of representing feedback loops. Modelling situations over time is directly addressed by simulation, e.g., discrete event simulation, time-stepped simulation, continuous simulation, or system dynamics (Fujimoto, 2000). Simulation models can include feedback loops; however, the existence of feedback loops is dependent on what was programmed to be a part of the model, not the fact that it is a simulation.

A choice then must be done with regard to closed form models – which are built to run without human intervention – and Human in the loop models. Closed form models are easier to use and avoid the uncontrollable variability of human decisions inside the model run. Human-in-the-loop models allow for simpler formal models by substituting available humans' mental models for portions of the total model. Human-in-the-loop models require increased complexity in their use to mitigate human variability and simply because of the increased staffing demand.

Other issue to be addressed is the Complexity; more complex (i.e., complicated) models can support finer granularity. Finer granularity supports, but does not guarantee, more precision and accuracy (Sokolowski, 2010; Tolk, 2012); accordingly, more complex models require more input data and are harder to examine for problems. Simple models usually run faster and take less time to set up and analyse. A model of a complex adaptive system is different from a complicated one. Indeed, the underlying real-world system that is the subject of a PMESII model is a complex adaptive system; however, the PMESII model may or may not be constructed to address typical complex adaptive systems questions (Hartley, 2015).

The problems specific to modelling DIMEFIL/PMESII factors can be divided into four categories: variables, relationships, invariants, and data. So it is necessary to answer the following questions:

- Variables: What are the relevant variables and who says so? Which variables influence each variable and who says so?
- Relationship: What is the functional relationship between influencing variables and influenced variable and who says so? Which relationships are

deterministic and which are probabilistic and who says so? What are the distributions for the probabilistic relationships and who says so?

- Invariant: Which of these things are invariant with scenario because they describe “human nature” and who says so? How do the non-invariant things vary with scenario variations and who says so?
- Data: What are the proper data to use as inputs and who says so? What do the “answers” mean and who says so?

These problems are compelling and they impact the creation of models and the level of believability in their results, and make hard to build and use DIMEFIL/PMESII models. However, real people (governments) do make decisions in the problem space that DIMEFIL/PMESII models should address, and so, absent a formal model, these people use mental, conceptual DIMEFIL/PMESII models, which means that initially any formal model is based on a mental model; furthermore, a formal model can be more easily viewed as separate from the user and, thus, be used as an advisory tool.

For what concern Verification and Validation (V&V) of PMESII models, V&V itself consists of processes that are difficult to perform for any model, with the corollary that a complete verification and validation of large simulations is virtually impossible. However, V&V for PMESII models must possess three key features (Hartley, 2015):

- continuous, in the sense that they occur throughout the phases of model conceptualization, development, deployment, operation, refinement. However, this feature is applicable to any V&V process (Youngblood et al. 2000; IEEE 2007; Roza et al. 2012; Bruzzone et al. 2017b; MSG 139 final report, 2018);
- entrenched, meaning that it must be ensured that the users do not violate bounds such altering parameter settings, initial conditions or model choice (employ an inappropriate model);
- people-centric” i.e., deal with education and training of model creators, users, supporters, customers).

However, it is important to realize that the particular humans who are “in the loop” are part of the model. Their expertise (or lack thereof) informs their mental models which guide their actions. Some effort must be expended in identifying and taking into account the effect they have on the results of the overall model.

In such perspective, the Modelling & Simulation User Risk Methodology (MURM), as developed within the frame of NATO MSG 139 (Youngblood et al., 2018) is able to assess the probability that inappropriate application of M&S results for the specific intended use will produce unacceptable consequences to the decision maker. This calls for the necessity to optimize the use of V&V resources to minimize risk associated with the application of M&S during the development of systems. In any case, it is important to keep in mind that the level of fidelity of a PMESII model to the real world cannot be expected to be as high as that of a kinetic model - we simply do not know enough about DIMEFIL/PMESII interactions to produce theories concerning these interactions that are as good as our theories about kinetic interactions (Hartley, 2015); for the reasons above, such models will be affected by an inferior knowledge when compared to kinetic models, and to the bias of value judgement. V&V toward PMESII should be able at least to register and possibly measure, at any moment of the model development process, any such influence.

In conclusion, the DIME/PMESII taxonomy, with DIME integrated with Financial, Intelligence, and Law enforcement yielding DIMEFIL, and PMESII integrated with PT (Physical environment and Time), as a general concept is entirely adequate. Having DIMEFIL stand for all of the intervention options and letting PMESII stand for a set of descriptors of the situation, this allows us to organize our thinking when modelling Hybrid Warfare.

1.5 MODELS AND SIMULATION RELEVANT TO HYBRID WARFARE

Having go past the necessary taxonomy, the next two paragraphs presents an extensive - however incomplete - review of multi-agent models of armed conflict of Irregular Warfare (IW), Military Operations Other Than War (MOOTW), and social behaviour models and simulations developed in the United States and in Europe since mid-1990s, in order to provide a general understanding of research trends in this domain. Most models selected can be characterized as increasingly mature efforts to develop basic multi-agent technologies for specific conflict contexts, like peace support operations like post-Operation Iraqi Freedom (OIF) in Iraq and International Security Assistance Force (ISAF) mission in Afghanistan. Some are modelled into validated decision or analysis support systems; none relies on either standalone narrative or mathematical analysis: they all include concepts of agency, purpose, actions and interactions. Doctor Armando Geller (2016) provided a survey of those models, and NATO ET 43 Working Group deemed those models relevant to Hybrid Warfare. What follows it is a review of the current M&S tools relevant to Hybrid Warfare modelling, built in US and in Europe. In Appendix 1 it is reported a table which reports the main topics of the models.

To facilitate model review, ET 43 has broken down the description of each model into three parts, corresponding to three stages of the life cycle of a model as: Vision, Development, Use.

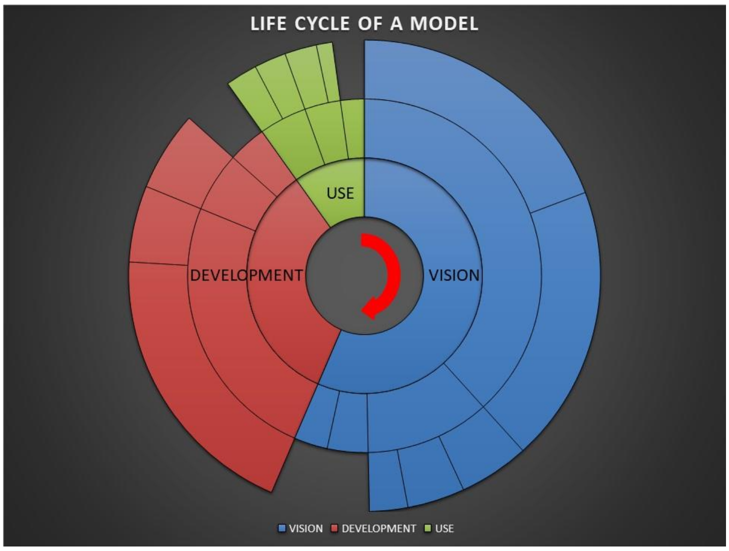


Figure 18 – Visualization of a Model's Life Cycle

Vision: The first part dissects the vision—the purpose—that spurs the development and usage of a model. It summarizes practical and theoretical needs that give rise to a model; determines whose needs the model is designed to meet, who has built the model, and who has funded the development effort. It also discusses the uses for which the model is built, be it decision and analytic support, theoretical exploration or technology demonstration. Finally, vision examines the anticipated life cycle of the model and how the model is meant to integrate with existing platforms.

Development: the second part, labelled development, is dedicated to making sense of the components of the model and the data and technology that go into building the model. In this part it is defined the scope of the model and detail various types of model agents and the model environment, and interactions between agents and the environment and between subsequent states of the environment.

Use: the last part is called use. Here we delve into model verification, validation and accreditation efforts, model releases, applications to date, and evaluation by users, developers, sponsors and third parties. Finally, the known strength and the known shortfall of the model/simulator are outlined.

1.5.2 North American Models

In this section we will describe 6 prominent models of conflict developed in the US:

- Regional Threat Evaluator (RTE);
- Senturion;
- Political Science - Identity (PS-I) modelling platform;
- Afriland & Rebeland;
- FactionSim & NonKin Village;
- A model of political economy of Afghanistan.

Regional Threat Evaluator (RTE)

Vision: In a joint effort, Defence and Academia developed the Regional Threat Evaluator (RTE), as a multi-agent network model of state failure (Louie & Carley 2008). Research on state failure attracted US government funds because by mid 2000s, defence establishment, homeland security agencies and intelligence community had quietly replaced simplistic explanations of international terrorism like "They hate our freedoms" with more nuanced, but empirically shaky, hypotheses, linking terrorism incidents to "grievances" of populations who were supposedly trapped in a vicious circle: dysfunctional states failed to provide basic services to their citizens; thus, radicalizing individuals, some of whom would resort to terrorism, weakening the state ever more to "failure", at which point the state would crumble and turn into a safe haven for terrorist groups.

RTE evaluates answers to questions such as: How does the likelihood of state failure change in the event of a natural disaster? How do increased levels of terrorism in a country affect the likelihood of state failure? These questions mean that at least in theory, the model was designed to address the link between terrorism in weak states such as Sudan, Pakistan and Afghanistan. The model is based on the integration of multiple theories of social, psychological, and economic behaviour that collectively account for why an agent takes action and what actions the agent chooses to take.

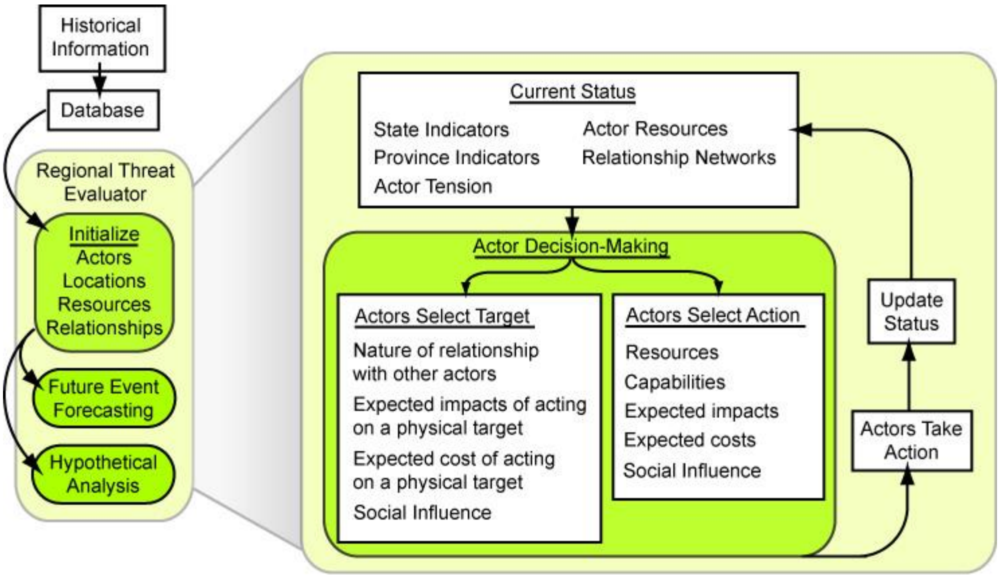


Fig. 19 – RTE conceptual model (Center for Computational Analysis of Social and Organizational Systems - CASOS)

The basic idea behind RTE is that inter-group conflict is due to a combination of tension and social comparison, the effects of which can be modulated by social pressure. Perceptions of high tension and relative disadvantage with respect to other agents induce agents to engage in hostile actions whereas lower tension and higher advantage lead them to non-hostile actions. An influential agent can exercise influence over other agents to escalate or de-escalate the impact of tension and social comparison in their behaviour. Specifically, an agent who is influenced by others who themselves are tense or feel deprived feel tenser and more deprived than an agent surrounded by others who are less tense or less deprived. Social influence derives from shared attributes such as culture, knowledge, borders and goals, and co-evolves with those attributes. It follows that the more heterogeneous a population and the more the lines of differentiation, the greater the potential for hostility. When agents decide to take action, the action and targets are selected using a bounded rationality cost-benefit analysis subject to resource constraints. The costs and benefits of taking a particular action against a particular target are also modulated by social influence. Thus, agents are more likely to take the kinds of actions against the kinds of targets that social pressure suggests are appropriate and will be sanctioned by other agents for inappropriate action or target choice.

Development: in RTE, bounded rational agents interact and take actions to achieve goals. When agents act, they take into account what resources they have available, the cost and benefits of the action, and the opinions of others by whom they are influenced. Agent actions influence the likelihood of state failure at the national level, measured by a composite index of the following factors: lack of state legitimacy, potential for province secession, hostility, tension, level of corruption, level of terrorist activity, level of criminal activity, level of foreign military aid, and lack of essential services. State failure is measured at the province level by similar indicators. The model uses real-world data to ground the initial model parameters. Actors, or agents, then proceed to interact and take actions that consume or generate resources. Agent activities lead to changes in agents' states and resources, non-agent targets, and state failure indicators. For example, forced migration of a population from one province to another is likely to decrease tension in the province they have left, increase tension and hostility and decrease essential services in the province they have migrated to, increase tension in the population that migrated and decrease their resources. Data used to parameterize the initial conditions of the model and limited validation of model outputs for the cases of Indonesia and Thailand came from 32 different sources, among them: national agencies like Indonesia-Tourism.com, international organizations as the United Nations, the World Bank and the International Telecommunication Union, US government agencies such as the Central Intelligence Agency and the Department of Energy, news services such as the Bangkok Post and British Broadcasting Corporation, research and academic institutions such as Terrorism Knowledge Base and Institute of Southeast Asian Studies, and corporate and labour groups like Netcraft. Additionally, specific information on relevant entities and provinces are drawn from online news sources like the Washington Post and web services like Wikipedia. These data were used as a basis for 150 state indicators, 60 province or region indicators and 30 entity indicators used to initialize the simulation model. Regional experts on Indonesia and Thailand were also consulted.

Use: Regional experts from the Defence Intelligence Agency (DIA), the Office of Naval Research (ONR), and the US Pacific Command (PACOM) were put together by DARPA to face-validate the model. Face validation by these experts focused on whether the conditions represented in the model produced the expected outcomes in terms of the indicator variables overtime. However, RTE is based on an eclectic conglomerate of theories that raises questions of coherence; its scope is not entirely clear, for some parts can be read as if it is a conflict theory. Furthermore, it is not readily clear which parts of the model ontology are supported by evidence and data and which are not.

Senturion

Vision: another joint effort between Defence and Academia, Senturion is a game-theoretic platform for predicting outcomes of competitive and adversarial interactions. The US DOD stance on game-theoretical modelling has oscillated from ardent support during the cold war, to neglect and benign suspicion in late 1990s; however, the resurgence and relative failure of data mining and machine learning approaches to provide insight on dynamics of adversarial and cooperative interactions in organizations, opened a small venue for behavioural modelling approaches. Senturion is a simulation capability that analyses the political dynamics within local, domestic, and international contexts and predicts how the policy positions of competing interests will evolve over time; the developers of Senturion view computational modelling as a way to improve understanding human behaviour and decision making (Abdollahian et al. 2006). Computational modelling should be based on reliable simulations of human behaviour that can be applied for unbiased predictions of potential threats, and form the basis of courses of actions as responses to these threats.

Senturion is a platform and predictive analysis software to facilitate and pool the knowledge of subject matter experts in the government and academia. Senturion synthesizes political science and microeconomics into a real-world decision making tool. Instead of a statistical or probabilistic approach to predictive modelling, Senturion uses algorithms drawn from game theory, decision theory, spatial bargaining, and microeconomics. The combination of expert interviews, simulation, and game theory draws upon some of the most highly regarded approaches to predictive analysis. But in essence, Senturion is a multi-agent model that relies on dynamic and recursive estimation to mitigate risk by anticipation, to explain outcomes, and identify courses of action.

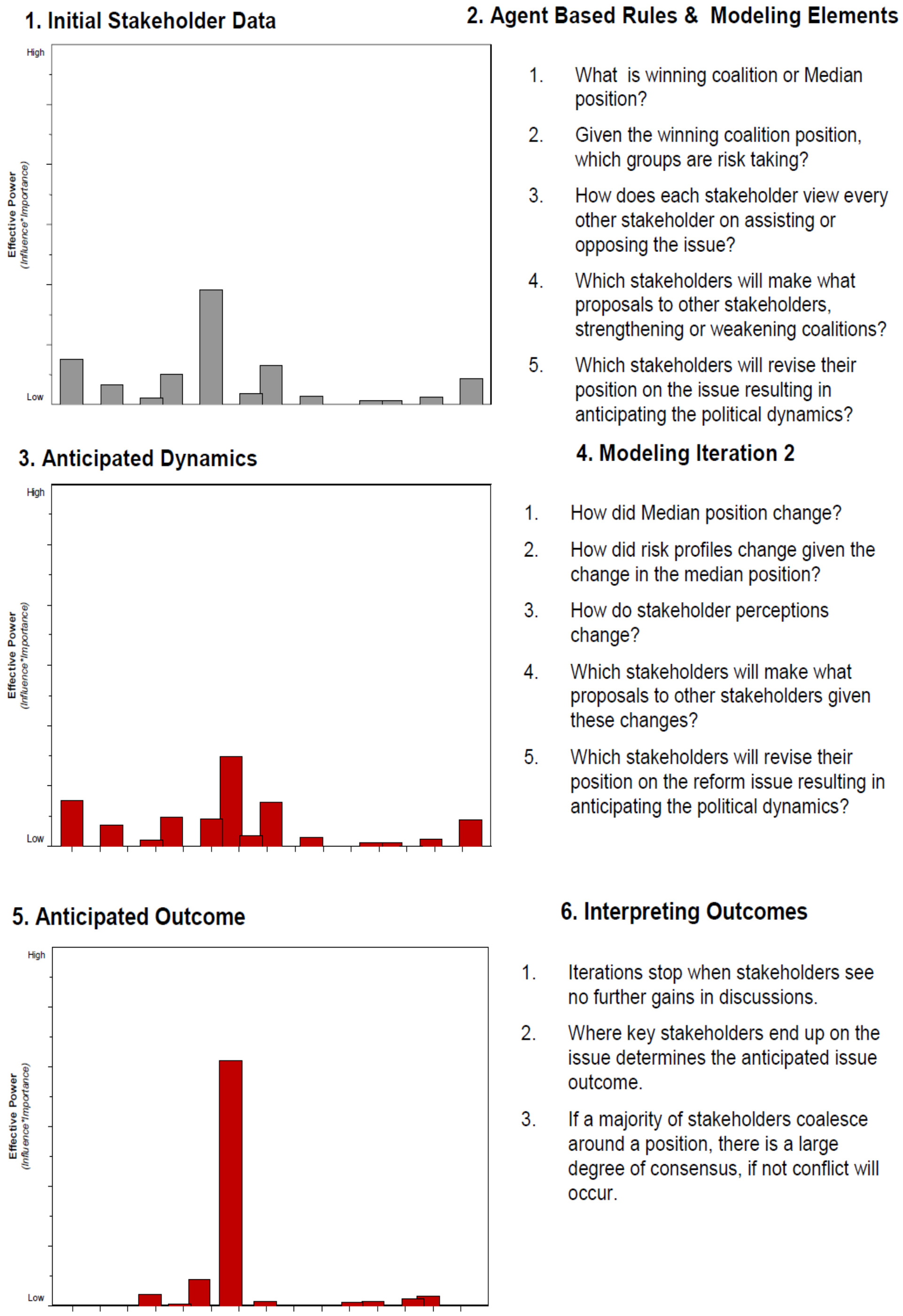


Fig. 20 Senturion: Six steps of the Modelling Process (from: "Senturion: Predictive Political Simulation Model" (2006), Defence and Technology Paper, 32, Centre for Technology and National Security Policy, National Defence University).

Senturion allows framing the relevant political issues and enriching them with subject matter experts' knowledge and data; its methodology helps to improve subject matter experts' track record by diminishing bias and increasing accuracy. Furthermore, Senturion quantifies qualitative stakeholder analysis in adversarial or competitive settings like negotiations, bargaining, and coalition and consensus building. For example, it can be used to model the negotiating stance of parties in mergers and acquisitions, collective bargaining agreements and sharing natural resources.

Development: Senturion modelling cycle (fig. 20, above) works as follows:

1. Initial stakeholder data;
2. Multi-agent modelling;
3. Anticipated dynamics;
4. Modelling iteration;
5. Anticipated outcome;
6. Interpreting outcomes.

Iteration stops once stakeholders see no further gains in discussions; if a majority of stakeholders coalesce around a position, there is a large degree of consensus, if not conflict will occur.

Agent behaviour in Senturion is modelled after theories that provide evidence for how agents behave in the real-world political processes. Agents maximize payoffs and seek to create coalitions. While Senturion uses multi-agent modelling more as a heuristic than a social modelling approach, it transcends traditional stakeholder approaches by providing a consistent and systematic framework for exponentially increasing networks of interactions without reduction or oversimplification of the problem. For a given political issue, Senturion simulates the iterative political decision making calculus among stakeholders with different interests in and varying influence on the political process. It predicts how these bargaining dynamics play out across a network of political relations over time. The result is an analytical assessment of the likely extent of change and of the degree of stakeholder support for this outcome without relying on an ad hoc assessment.

Senturion uses a rigorous elicitation mechanism to collect data from subject matter experts in order to assign stakeholders in a political landscape multiple attributes on their political position and potential influence, and their willingness and ability to expend political, economic, social and military resource on the issue. It assesses and explains how stakeholders arrive at a decision; evolve their interests and positions on an issue over time, or how a political outcome is achieved in within local, domestic, and international contexts by a sequential combination of elements relevant to the decision process. Senturion thus can provide a consistent framework for objective analysis of stakeholder politics, rather than relying solely on individual expert opinions about political outcomes (Abodollahian et al, 2006). Of course, analytical transformations cannot compensate for poor data. The reliance on stakeholder data - crucial to understanding human behaviour and stakeholder motivations - limits the temporal forecast horizon to approximately two years, as certain data elasticities can propagate error over time. In other words, the likelihood of exogenous shocks over the stakeholder list increases over time, and after two years becomes quite high. That said, Senturion allows the analyst to examine political dynamics to, first, gauge whether the policy options are politically feasible as designed and, second, identify tactics to shape the political environment and achieve a more favourable outcome; in conclusion, it can provide an assessment of multiple courses of action with a higher degree of confidence then previously available.

Use: having described the methodology underlying Senturion, we now examine two of its famous applications: Operation Iraqi Freedom and Iraqi Elections of 2005.

Based on the aftermath of OIF in April 2003, it was predicted that the situation in Iraq would worsen throughout 2003 and 2004 in terms of Iraqi attitudes toward U.S. presence as well as insurgent activity (Abodollahian et al, 2006). While the Senturion simulation indicated that OIF would produce a quick regime change, Saddam's well-trained former military core was expected to provide the basis for violent and persistent resistance. The simulation anticipated that this resistance would receive broad and growing political support from numerous and otherwise opposing factions within Iraq, as well as that the Initial Shiite neutrality to the United States was expected to evolve into active hostility for important factions, including Al-Sadr. Ahmed Chalabi, an Iraqi dissident during the Saddam regime who was sponsored by the United States in post-war Iraq, was not expected to be a reliable ally for the United States over time. Continued U.S. military presence was expected to unify many Sunnis and Shiites against a common foe, the U.S. military forces on the ground. While these findings have become a more generally accepted explanation of events after the fact, there was substantial disagreement about the likely course of events as predicted by the Senturion simulation prior to OIF.

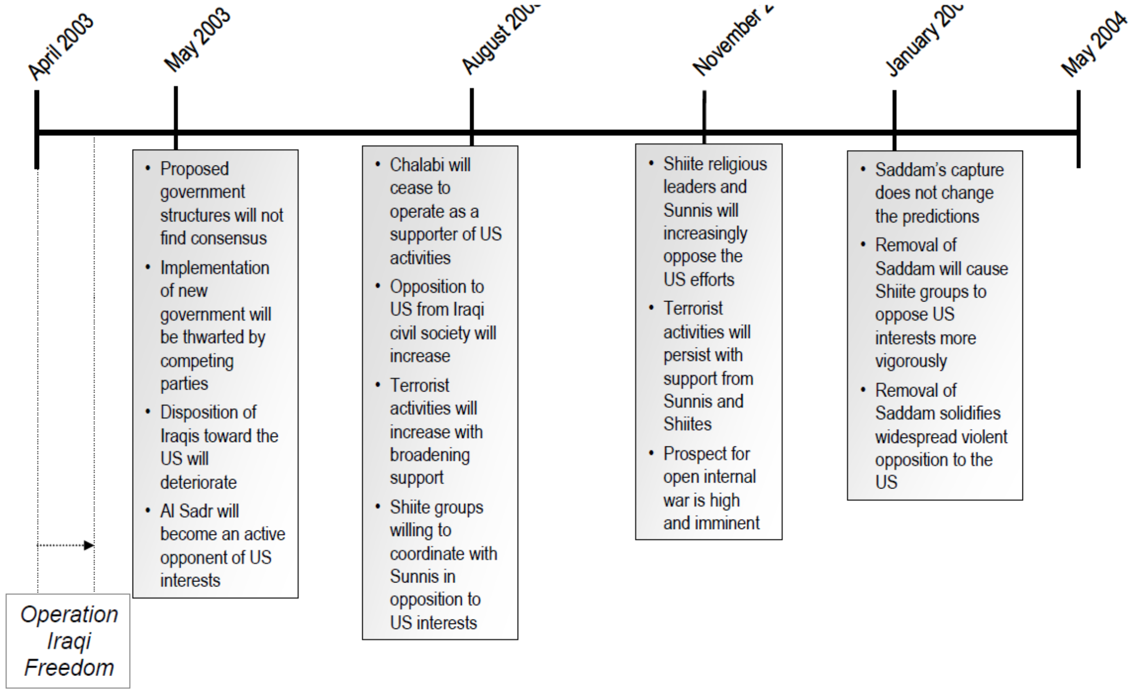


Fig. 21 Track record of Senturion predictions on Iraq (from: "Senturion: Predictive Political Simulation Model" (2006), Defense and Technology Paper, 32, Center for Technology and National Security Policy, National

Senturion simulations provided detailed forecasts regarding how stability and regime change in Iraq would unfold as a consequence of OIF and subsequent actions. The model produced very specific predictions about the behaviour of individual stakeholders and accurately captured the timing of unexpected defections as well as the potential support from unexpected allies. Applying Senturion to an unfolding political situation was a success, considering the limited access to subject matter experts (Abodollahian et al, 2006).

In the case of Iraqui election in 2005 (Abodollahian et al, 2006), only open-source data from subject matter experts from the Intelligence Community and Washington Institute for Near East Policy have been used. The work focused on support for the January 2005 elections in Iraq, and all findings and predictions were generated using Senturion only. The largely pessimistic forecast for the elections held up well when compared to the actual flow of events. Table 1 below, summarizes all of the predictions based on data collected by the end of December 2004 and compares them to actual events that unfolded over the following two months.

Predictions *(Based on 12/30/2004 Data)*	Actual Events	Date of Actual Event
Insurgents will continue scope and pace of attacks.	Repeated attacks by insurgents continued through the elections.	1/31/2005[15]
Strong supporters of the elections, particularly Sistani's followers and secular Shia, will participate in the election.	Sistani's supporters and secular Shia voted in large numbers in the election.	2/1/2005[16]
Sadrists will be indecisive about supporting the election despite positive signs during January.	Sadrists straddle both sides of the election issue, neither boycotting nor actively opposing the election, but also not endorsing the process.	1/31/2005[17]
Secular Sunnis and Sunni tribal elders will remain neutral toward the election.	Sunnis disproportionately stayed home during the election, while not actively opposing the process.	2/1/2005[18]
Kurds will strongly support the election.	Kurds turned out for the election in large numbers.	2/1/2005[19]
Tension will remain high between Kurds and Shia.	Tension between Kurds and Shia on future of Iraq appears to remain high despite the election.	1/31/2005[20]
Zarqawi and foreign insurgents will have little success in undermining support for election in January.	Election went forward with high Shia participation, despite attacks by insurgents.	2/1/2005[21]
World Bank and IMF will pull back support of the election.	Timing and willingness of World Bank and IMF reconstruction efforts in Iraq unclear.	1/28/2005[22]
France, Russia, and Germany will increasingly support the election.	France and Germany praise the Iraqi election. Russian response ambiguous.	2/2/2005[23]

Table 1. Track record of Iraqi Election (from: "Senturion: Predictive Political Simulation Model" (2006), Defence and Technology Paper, 32, Center for Technology and National Security Policy, National Defence University).

Its known strengths rely on the fact that model's outcomes have been validated in approximately 300 scenarios where it was able to provides insights into complex decision making and to identify second and third order effects. The methodology could be integrated with and leverage from other approaches such as social networks and system dynamics.

Its known limitations are given by the fact that the model requires high-quality data and extensive subject matter expertise. This limitation is mitigated by a Monte Carlo analysis on the SMEs' input to produce a confidence interval on the outcome

However, while Senturion offers unique capabilities for decision making and prediction of political events, it is hamstrung by the following shortcomings:

- The process of moving from agent decisions to political outcomes if not clearly defined.
- The game theoretical model that underlies Senturion does not theoretically guarantee that using Senturion diminishes subject matter experts' bias.
- Answers by subject matter experts' to questions that delineate agents' preferences and issue salience to them result in a hard-wired system without facilities for sensitivity analysis or stochasticity.
- Except for ad hoc calibration, Senturion does not theoretically guarantee that prediction error rates fall within a reasonable margin or that it does better than pooled subject matter experts' predictions.

PS-I (Political Science—Identity) modelling platform

Vision: the developers from University of Pennsylvania (Ian Lustick and Vladimir Dergachev) conceived PS-I with the intent to make available to political scientists and other social scientists (with no programming skills and no previous background in formal modelling), an accessible agent-based modelling tools for exploiting theory, in order to analyse political phenomena. PS-I platform deals with issues such as how institutional frameworks determine goals, how violence arises, and what the trajectories of identity movements are (Lustick et al. 2004). Drawing on the constructivist identity theory (Onuf, 1997,1998 & 2002) to determine agent behaviour, PS-I tests popular theoretical propositions like "power-sharing explains the containment of secession better than repression." PS-I simulation platform creates an artificial state in order to explore patterns of secession and secessionism through constructivist identity theory. This artificial state captures certain composite features of multicultural or multi-ethnic countries that may encounter threats of secession without corresponding directly to any particular country. Therefore, the simulated state should be regarded as a specialized tool that is useful for exploring the extent to which some patterns of ethno-political mobilization and secessionism can be accounted for by focusing specifically on "identitarian" processes and pressures. As the simulation moves forward in time, the rules governing agent behaviour permit the rotation and trading of identities as functions of changing advantages and disadvantages associated with individual identities and with local conditions. The model evaluates a variety of propositions on polarization and alienation, regional concentration, and tension between alienated individuals and others under the following institutional schemes: repression, responsiveness, and representation. The simulation experiments explore relationships among institutions, ethno-political mobilization, secessionist activity and secession. It also evaluates the effects of the following three policy scenarios: repression; increasing responsiveness; power sharing by granting different degrees of autonomy to the potentially secessionist identity. Simulation results show that institutions, ethno-political mobilization, secessionist activity, and secession are strongly inter-correlated; that repression decreases secession; responsiveness produces more mobilization, but not necessarily more secession; and power sharing, representativeness, and semi-autonomous institutions decrease secessionist activity. These results indicate that non-coercive policies for reducing secessionism and secession may work only at the "cost" of a state accepting a significantly larger role in the public political arena for political expressions of historically "out-group" identities.

Development: PS-I agents are inactive, immutable, bounded rational, but not strategic. They are divided into two broad classes of agents, Influential and Basic; each endowed with a repertoire of identities. The Influential class is further divided into three levels. Bureaucrats are drawn from Influential, exhibiting different levels of influence. They all have the incumbent identity. A small number of top bureaucrats have a level 4 influence; mid-level bureaucrats have influence level 3; lower level bureaucrats have a level 2 influence. There are three national identities, and depending on their role, region, and parochial identity, agents can have a higher or lower identity repertoire. There are also loyal opposition agents. All agents incorporate national, particularistic, and locally prevalent identities. An activation rate governs how "activated" agents view their own identity; thus, defining how prominent a particular identity is in a region. Agents are placed in a Moore neighbourhood[1] and change identity as a result of interactions with others filtered through biases that represent a "mass-media" mechanism.

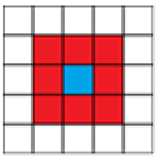


Fig. 22. A Moore neighbourhood

[1] In cellular automata, the Moore neighbourhood is defined on a two-dimensional square lattice and is composed of a central cell and the eight cells that surround it (https://en.wikipedia.org/wiki/Moore_neighborhood)

Each agent registers the activated identities and influence levels of its neighbours but not the composition of their repertoires. Simple calculations of relative “identity weight” lead each agent to either remain activated on its currently activated identity; rotate into activation an alternative identity from its repertoire; substitute an identity from outside its repertoire for one inside its repertoire; or, in cases of a fairly overwhelming discrepancy in favour of an identity not in its repertoire, actually substitute and activate on an identity previously absent from its repertoire.

The state is divided into four quadrants of overlapping identities that represent relationships of multinational democracy based on principles of federalism, multiculturalism or both. Each quadrant has a radiating web of bureaucracy. The southeast quadrant, however, is different from the others. It is controlled by the state, but inhabited by a disgruntled minority. Bureaucrats in the southeast have not incorporated the identity of the disgruntled minority and therefore cannot “understand” and respond to them appropriately.

Use: as a theoretical model, PS-I does not distinguish between violent or non-violent mobilization. However, it says a great deal about how evolving organizational patterns and trajectories might lead to conflict. The broadest and most compelling finding emerging from PS-I results is that explanations for variation in amounts of ethno-political mobilization, even by members of communities that seem primed for secessionism, cannot be expected to correspond to explanations for patterns in the variation of amounts of secessionism or outright secession. When compared to three historical cases of secessionism in Québec in Canada, Corse in France, and Kashmir in India, these results appear robust; in the case of secession of Ukraine eastern’ provinces bordering Russia and the seize of Crimea (2014), would be interesting to understand how an exogenous force (i.e. hybrid warfare) can deteriorate the political situation of region which however always enjoyed a high level of autonomy from the central government. However, against secessionism, Nation-states need to find trade-offs between repression and representation. Note that while the before mentioned Regional Threat Evaluator (RTE) uses a mix of social psychology theories that link individuals’ material position to their behaviour through perceptions of social advantage and disadvantage to investigate state failure, in contrast PS-I brings identity to the fore to estimate probabilities of secession, a specific outcome expected in some form of state failure. A state can fail without ever experiencing secession, while another state might have to grapple with secession exactly because it has been successful in empowering a minority to demand separation, or another state could experience secessionism because have been targeted by forms of hybrid warfare. As such, at least in theory, PS-I can be used to model social and political fragmentation in countries with more stable governments and institutions that do not seem at the brink of state failure.

Issues:

- PS-I is highly unspecified. For example: Agents can be representing individuals, families, villages or any unit of political aggregation that may seem appropriate.
- PS-I basis for changing identities is not well-grounded in evidence or theory.
- PS-I cannot produce emergent behaviour. For example, regional arrangements are hardwired into the model: one region is the core, two are loyal, and one is disgruntled.
- PS-I results and on the basis they are achieved are not subjected to even rudimentary tests of robustness. For example, secessionism is measured by the number of cells that border a given cell. How much would the results change, if this definition were altered?

AfriLand and RebeLand

Vision: modelling approaches in international relations often underspecify political actors, polities and externalities. On this regard, Cioffi-Revilla and Rouleau (2009, 2010) explored such issues in two related multi - agent models called “RebeLand” and “AfriLand”, at different levels of analysis. RebeLand is a model of an island polity with comprehensive structure and processes. AfriLand is a model of a region consisting of ten neighbouring polities. RebeLand aims at modelling socio-political behaviours in a coupled socio-natural setting; AfriLand, on the other hand, aims to analyse socio-cultural and environmental dynamics that transcend national boundaries and have a regional impact. RebeLand and AfriLand are thought experiment models that are intended to replay HADR (Humanitarian Assistance & Disaster Relief) scenarios in a local framework such as amongst herders and farmers. None of the models has empirical basis or an integrated modelling design. AfriLand is built atop RebeLand to represent the target system of East Africa (its envisioned customer was US AFRICOM).

As a polity consisting of a society and a government for managing public issues through policies, RebeLand dynamics rest on the idea that emerging public issues lead to varying levels of stress to which governments respond with stress-reduction policies. A government's response capacity depends on available tax revenue that depends on job availability. Increasing levels of stress among the population and the government's increasing inability to formulate mitigating policies can lead to the emergence of unrest and rebellion. Model dynamics derive their importance from coupling social and natural phenomena.

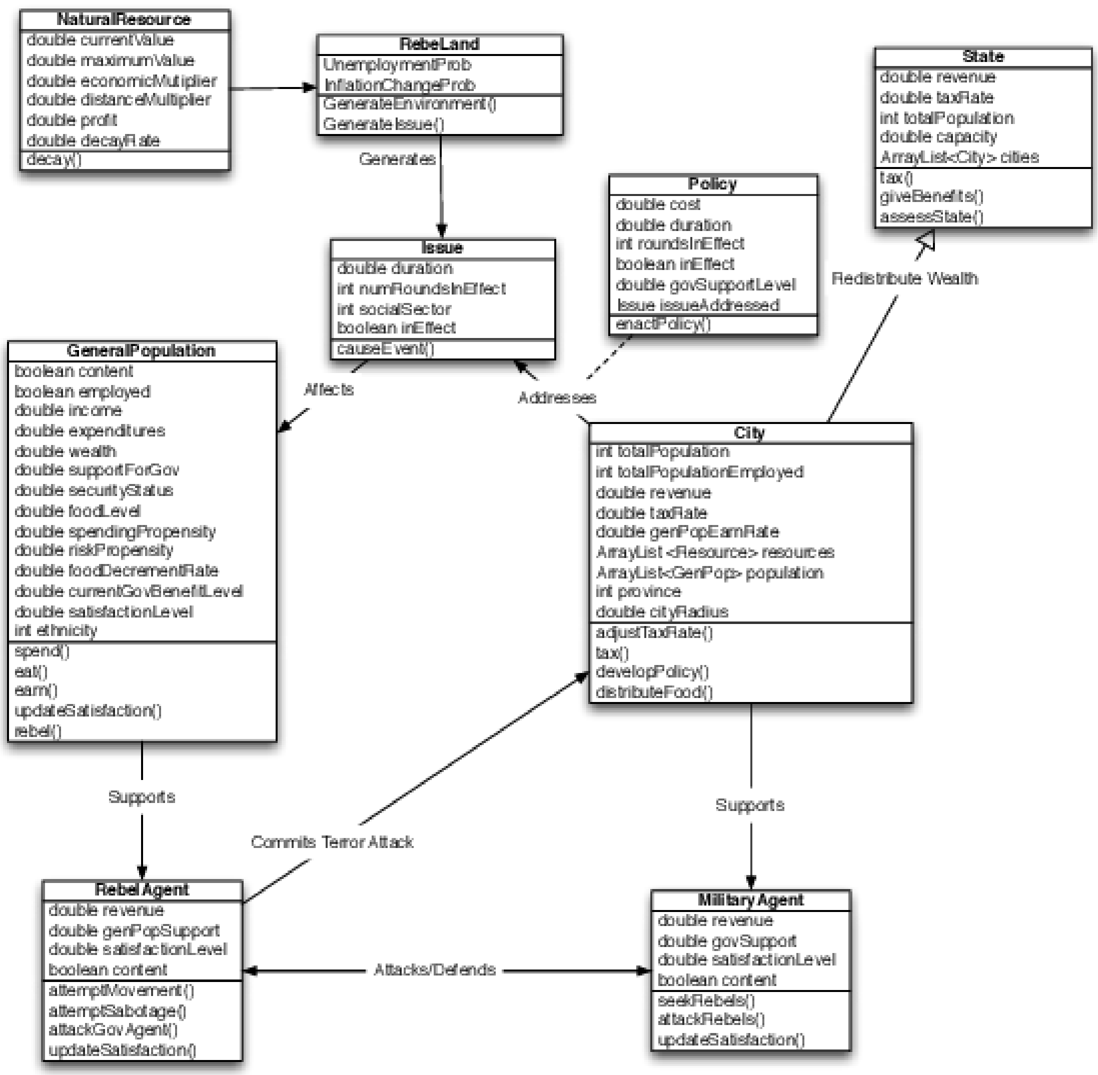


Fig.23 - UML class diagram of the RebeLand-type polity model representing each of the ten countries in AfriLand. Source: Cioffi-Revilla & Rouleau (2009).

Development: RebeLand consists of primary and secondary agents. Primary agents are the general population, cities and the state. Secondary agents include rebels recruited from the general population, rebel groups and governmental security forces. Each AfriLand polity functions in the same way as RebeLand. Borders among polities are explicit, migratory and permeable. RebeLand examines the stability and failure of a state made up of three provinces, each with population centres, resources, and transportation and communication networks, through three different setups: stable, contentious and unstable. In the stable setup, a happy population pays taxes, so the government can adequately respond with policies to societal issues. In the contentious setup, the population supports the rebels in sudden outbursts, because of inadequate government policies to solve societal issues. In the unstable scenario, government policies are completely inadequate, so the rebels take over and the state fails. Stability, instability and failure evolve from agent interactions; they are not predetermined outcomes. RebeLand is a light theoretical model and does not use any real data.
Use: It is not known whether the model has found any users other than the developers themselves. AfriLand and RebeLand are based on intuition and are therefore theoretically and empirically underspecified. None is based on real data; none is validated.

FactionSim and NonKin Village

Vision: for the creators of FactionSim (Silverman, Bharathy and Kim, 2008), the starting point was the necessity for HBM applications to increase the realism of the synthetic agents employed. That requires the employment of thick models, which can integrate scientific know how from psychology, sociology and political science. FactionSim is a comprehensive modelling suite made up of cognitive, social, physiological and economic layers that can configure diverse theories of the origins and resolution of cross-cultural conflict, because no unifying social science theory supports the development of a single coherent model of conflict for training or analysis. The overall goal was to model how actions carried in the DIME power can influence the PMESII status of a given country of interest. As a generic game simulator for social scientists and policymakers, FactionSim is intended to synthesize the social and behavioural models that are needed to recreate real world places or close facsimiles that are archetypal of real world cultures, in order to support autonomous agents carrying out their lives in an artificial society. According to Silverman, Bharaty and Kim (2008), analysts can use FactionSim to rapidly mock up classes of commonly encountered conflicts or opportunities for cooperation. As default settings, FactionSim contains a collection of such models including agents, groups, organizations, and natural and manmade structures. It allows editing agent profiles according to cultural identity characteristics and demographics properties of the population. The modular structure of FactionSim is model-driven and makes it reusable for various conflict contexts and situations, but does not force it to follow a particular multi-agent or other modelling approach.

NonKin Village (based on FactionSim) is an artificial society for cultural training in which trainees, often small-unit leaders and soldiers in squads or platoons, may learn the village culture through immersion and problem discovery and resolution. NonKin Village is populated by autonomous socio-cognitive agents whose behaviour is derived from social science theories. NonKin Village generator is a game world generator that brings life to agents of all factions in a “SimCity” style. It supports soldiers’ street-level interactions and dialog with village residents to learn their issues, needs and grievances, to assist them in countering the insurgents’ agenda, and to create a self-sustaining peace.

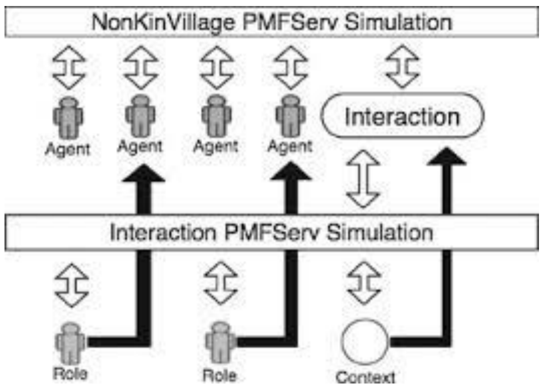


Fig.24 – PMFserv architecture (Silverman et al. 2008)

Development: a model called PMFserv deals with agent cognition in both Faction Sim and NonKin Village. PMFserv it is a human behaviour emulator that drives agents in simulation world, according to logics singled - out from the behavioural sciences (Silverman et al. 2008). It runs agents through the observe, orient, decide, and act (OODA) loop. Agents’ interactions are not hardwired into the system, so agents are capable of exhibiting emotional responses that deviate from “norms” in their conversation and transactions. PMFserv agents have profiles according to which they are instantiated and parameterized. Other model entities have mark-ups that allow agents to perceive and reason about the world. Subject matter experts' opinions and data on agents' past actor can also be used as guides for agent perception. Agents capture their own internal state and societal norms in a catalogue.

Use: PMFserv have been successfully employed in domestic applications (consumer modelling, crowd rioting) and international applications (Intifadah recreation, Iraq DIMEFIL-PMESII). FactionSim game generator and its suite of social science models have been successfully applied in the past to recreate communities in Southeast Asia, the Middle East, and the Horn of Africa. In over 200 statistical correlations with real world communities, the developers claim it has been proved to be over 80% accurate at recreating the conflict and cooperation decisions of leaders for and against the groups they manage and follower membership action choices. FactionSim can also be used in cultural training of the US military small-unit leaders and personnel at the tactical level for cultures and contexts for which enough anecdotal evidence exists to create a convincing outline of do's and don'ts, taboos, norms and conventions.

However, FactionSim cannot handle operational training and planning or policy analysis; the former because it is not geared for persistent joint operations at multiple levels; the latter because it does not have facilities to express emergent, anticipatory norms. Issues:

- The theoretical and data bases for Faction Sim and PMFserv that give rise to agent cognition and interaction processes are not articulated.
- FactionSim is focused on predicting the aggregate behaviour of the society it models instead of forecasting the behaviour of individuals it models.

A model of the political economy of Afghanistan

Vision: Human, Social, Cultural and Behavioural Modelling (HSCBM) program of the US DOD had funded Armando Geller at George Mason University to create a multi-agent model of the political economy of Afghanistan, and to explore links between licit and illicit economies in order to capture how they fuel processes of insurgency (Łatek, Rizi, Mousavi and Geller 2010). The project aims to advise on policy, operational and analytical questions, a sample of which is listed below:

- Policy: How important is drug trade to the livelihood of the Afghan population? How can we decrease drug trade in Afghanistan? How can we decrease its significance to the population?
- Operations: How many men and for how long are needed to eradicate poppy fields, interdict drug shipments in a given province and prevent cultivation shift to neighbouring or other provinces?
- Analysis: How much bribes and protection money from drug traders frequenting a given route will be gathered and by whom?

Development: this model is a country-scale, house holder solution multi agent simulation with explicit biophysical data layers and heterogeneous population of three million farmer households, twenty thousand small-scale crop traders, a thousand medium drug traffickers and fifty major traffickers. These agents interact with each other and the urban population on a set of regional markets subject to monitoring by the insurgents and security agents such as the Afghan National Police (ANP), Afghan National Army (ANA) and NATO assistance mission (ISAF). The environment for interactions and constrains for decision processes is empirically informed. Agents are adaptive in nature; ensure their own survival, and in a bounded rational manner maximize their income subject to the following factors:

- Farmers choose what crops to cultivate and when to sell and buy more of crops they have cultivated and buy those they have not. They account for historically smoothed local prices of different crops; expectation of climatic conditions; government policy; availability of farm labour provided by family members or rented out from locals; household food consumption.
- Traders are differentiated between opportunist, small scale traders and the more specialized opium traffickers and wheat wholesalers. The decision cycle for all traders is similar and includes monitoring a set of markets, collecting available buy and sell offers and determining the most lucrative trade opportunities; posting a buy or sell offer depending on the level of the stock of crops; and adjusting risk based on transportation costs, risk perceptions of losing crop shipments to bandits or government interdiction, the necessity to pay bribes if caught with illicit crops; and urgency to replenish the stock of each crop to the desired level.

- The government allocates forces to districts and to poppy eradication and trade interdiction as counternarcotic policies. Government agents can be corrupted by traders and farmers.

This project has innovated a customized approach to merge demographic and economic data in the war zone, and it informs the model by using statistical sampling methods for combining remote sensing data with local surveys, and recovering an "agentized" common data picture of the rural population in Afghanistan. This joined dataset has been validated with an independent source. Dataset merged include remote sensing data by the Oak Ridge National Laboratory (ORNL), Afghanistan Information Management Services (AIMS), and the US Agency for International Development (USAID) on agricultural economy production and rural population; quantity and price spatial panel data for various drugs markets by the United Nations Office of Drugs and Crime (UNODC); spatial panel data on security incidents in Afghanistan by the ISAF and behavioural surveys by the UN FAO.

Use: Out-of-sample validation has been performed by replicating province-level poppy cultivation intensity and pricing in major markets during 1998-2008 when played against real climate and security conditions.

1.5.2 European Models

In this section we review ten models developed in the EU:

- Combined Land Air Representation of Integrated Operations (CLARION), and his twin, Diplomatic and Military Operations in a Non-Warfighting Domain (DIAMOND);
- Peace Support Operations Model (PSOM);
- Strategic Management System (STRATMAS);
- PAX;
- Attitude changes and diffusion models;
- Humanitarian Assistance and Disaster Relief Models (HADRM):
- Common-pool Resources and Multi Agent Systems (CORMAS);
- Threat network simulation for REactive eXperience (T-REX);
- Simulation of Multi Coalition Joint Operations involving Human Modelling (SIMCJOH).

CLARION

Vision: Combined Land Air Representation of Integrated Operations (CLARION) models include a plethora of forces in various packages available to warring parties and cover the complete spatial and temporal dimensions of a conflict. CLARION was born in the mid-1990s out of the United Kingdom (UK) Ministry of Defence (MOD) need for an integrated campaign planning tools at appropriate levels of resolution, applicable to various types of conflict and robust enough to support an evolving processes of combat in a 20-year timeframe. The Defence Science and Technology Laboratory (DSTL) developed a suite of simulation models for campaign planning and analysis under the rubric of the high-level operational analysis (HLOA) program. CLARION and DIAMOND (Diplomatic and Military Operations in a Non-war fighting Domain) are two components of this software suite (Taylor & Lane 2004).

Development: CLARION at its core it is a two-sided model of land combat written in C++ and consisting of the following entities: headquarter; ground combat unit, often battalion or brigades of infantry and tanks, called close combat entity (CCE); reconnaissance; artillery; remote sensor; attack helicopter squadron; attack helicopter base; aircraft squadron; and aircraft base. Entities are grouped into proper military hierarchies and organizations that act as higher-level entities. Therefore, CLARION functions within a predefined command and control (C2) structure that helps model outcomes resemble reality more closely. Entities have local perceptions of the situation they face, augmented by information they receive from other friendly entities; they do not have access to ground truth, but rather to incomplete information acquired through their own intelligence, surveillance and reconnaissance (ISR) assets. Based on their information and goals, they define and execute sequences of scripted plans called missions characterized by activity type; operational, organizational and geographic constraints, time delays for assigning and communicating orders through organizations and criteria for success. Each entity tasks subordinate entities where applicable by a hierarchical task network (HTN) decomposition routine with reactive triggers and conditions that allow them to respond to enemy and friendly units’ success or failures. CLARION reduces the probability of unrealistic entity behaviour and simplifies the processes of mission construction by endowing each entity with default behavioural heuristics drawn from human intuition, for example, non-combat entities attempt to distance themselves from enemy combat units (Moffat et al. 2011).

Use: CLARION has undergone extensive validation.

- In an exercise in 1998, less than six months after CLARION 2.0 became available, CLARION outputs for several test scenarios were compared with predictions based on historical analysis. CLARION output on key measures of combat such as battle duration, casualty levels and advance rates broadly agreed with historical records. The exercise also helped CLARION remedy a flaw in its business logic: an attacker was required to destroy defending units it had defeated completely before advancing. Now the attacker simply pushes units it has defeated but not wiped.
- Another validation exercise pitted CLARION output against those obtained in human-run war games with similar force packages and geography of the battle space. CLARION outputs appear to be militarily credible.
- CLARION has been used within Analysis of Defence Capability (ADC), a rolling program designed to test U.K. military capabilities, to assess land campaigns since 1997.

DIAMOND

Vision: while CLARION focuses on the land campaign planning and analysis side, where two parties fight high-intensity conventional battles, DIAMOND (Diplomatic and Military Operations in a Non-war fighting Domain) is developed by DSTL as a high-level, multiple-party simulation model for analysing peace support operations (Bailey, 2003), focused on C2. DIAMOND generates mission and represents complex factional relationships and civil infrastructure in long-run scenarios. Like CLARION, it is developed as an object-oriented design, coded in C++.

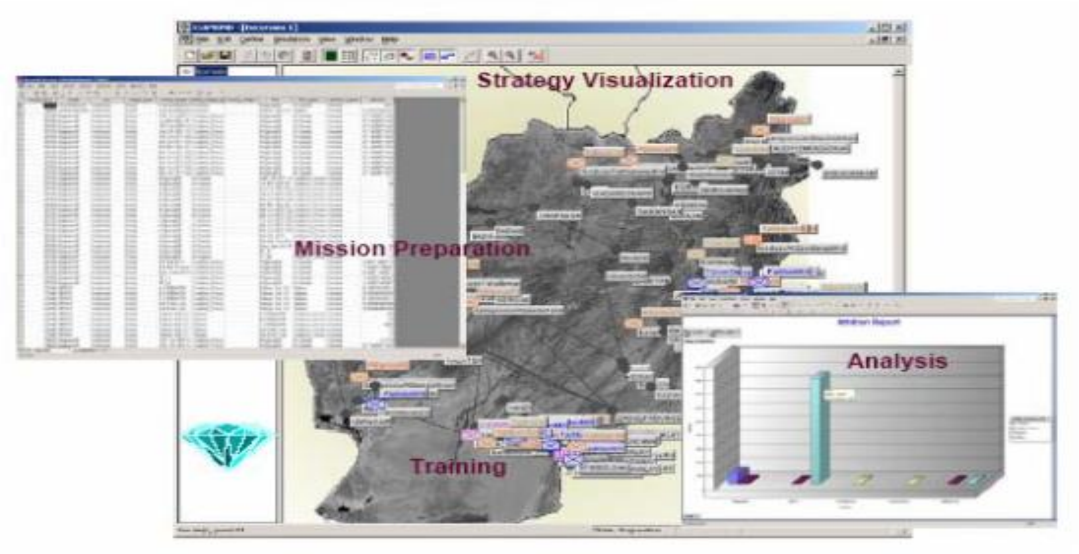


Fig. 25 - Diplomatic and Military operations in a non-warfighting domain (Curtis, 2005)

Development: DIAMOND includes the following entities:

- intervention forces tasked with peacekeeping and peace enforcement; armed forces of warring sides in a country or region called factions;
- civil organizations including international and domestic governmental and non-governmental organizations such as aid and relief agencies;
- commercial firms; civilians with different political affiliations and settlement status, for example, resident, refugee, evacuee and internally displaced.

Entities interact with one another and the environment and exchange or consume key commodities for survival and to pursue their goals. In DIAMOND, peacekeeping operations and missions by intervening forces follow rules similar to that used in CLARION for land combat planning.

Use: DIAMOND has undergone three validation exercises representing a remarkable mix of missions and variety of contexts with respect to the following real historical scenarios:

- Peacekeeping in Bosnia in 1995: the exercise tested the feasible boundaries of scenario sizes that can be represented and analysed by DIAMOND;
- Humanitarian aid in Mozambique in 2000: the exercise examined the humanitarian module of the model that distinguishes it from CLARION;
- Peace Enforcement in Sierra Leone in 2000: the exercise examined the conflict and factional interaction processes.

These validation exercises have shed light on the fitness of various components of the model. Since 2001, ADC (Analysis of Defence Capability) has also used DIAMOND to cover analysis of the humanitarian domain and it has been used as a starting point for further developments. UK DSTL funded an extension called the Hybrid War Model (HWM) that fully agentizes DIAMOND and endogenizes agent decisions at a more tactical scale (Moffat et al. 2011). The MITRE (MITRE is not an acronym) Corporation and Dynamics Research Corporation have produced a subsequently classified extension to DIAMOND called DIAMOND-US (Cipparone and Barry 2003), that has been used for scenario analysis and training by the Joint Chief of Staff J-8, US Army G-2 and Centre for Army Analysis (CAA). It was also introduced into the Naval Postgraduate School (NPS) curriculum (Cipparone et al. 2005).

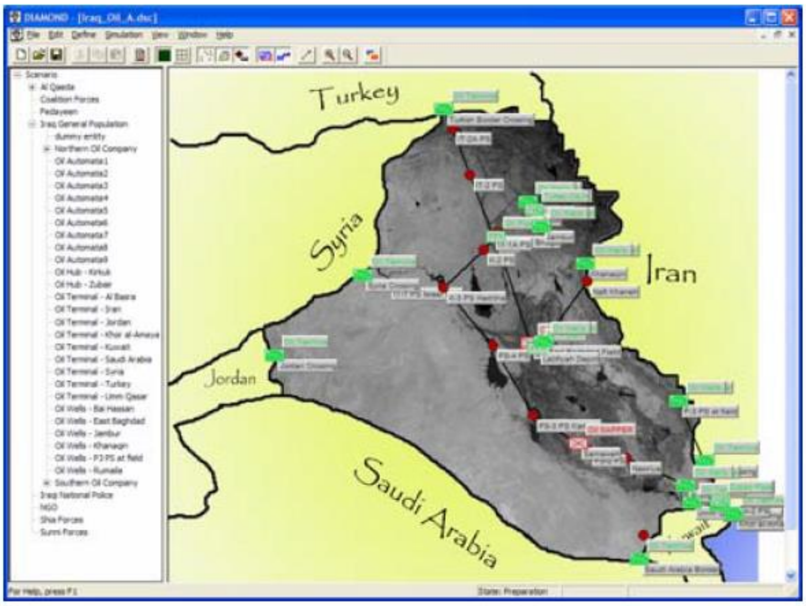


Fig. 26 - DIAMOND: Study of the Iraqi Oil Infrastructure (Curtis, 2005).

PSOM

Vision: PSOM (Peace Support Operations Model), built by DSTL for the UK MOD to support force development and training (Marlin 2009), covers security and stabilization and counterinsurgency operations in conflict and post-conflict environments, as an interactive war game for other government agencies in the UK and allied countries. Like its non-interactive predecessor DIAMOND, it supports multiple parties such as military forces, government agencies, factions in the host nation, and insurgents each with limited local perception and incomplete information. Unlike DIAMOND, PSOM can have some of its agents controlled by a human in the loop (HTL).

Development: PSOM characterization of NGOs, government agencies, private firms and humanitarian aid organizations as "factions" that are independent, aligned with insurgent factions or integrated with intervening forces or indigenous governments enables a realistic portrayal of their activities (Parkman & Hanle, 2008). The local population has specific dispositions toward each faction, and can be as diverse as needed to model real-world ethnic/religious groups such as the Kurds, Shia and Sunni in Iraq. Factions compete for power and legitimacy by "flipping" the population to their side. The behaviour of factions, especially intervening forces, originates from the UK and US counterinsurgency doctrine. Progress toward self-sustaining stability in a conflict area is measured in terms of population security, its consent to the presence and its fear of each faction, and state capacity to provide a basis for a functioning economy. PSOM factions execute military and civil courses of action, from the construction of power plants and administrative training, to ambush and IED emplacement. Strategic decisions are intertwined with operational decisions that influence civilian state variables. The resulting outcomes in this contest for power are measured as population consent for the presence of various factions that can provide security and vital services. This allows all factions to wage operations for the population "hearts and minds", by tactics that span from transition operations to outright terror. By focusing on the civilian population rather than on the interaction of military units, PSOM represents a wide range of political behaviours essential to create a comprehensive model. In order to provide a richer operational picture, PSOM represents as well the physical, human and organizational capital of a country. Finally, it records casualty metrics as the likelihood of violent death within the local and national population, the consent of the population to the activities of various factions, a measure of the level of state functionality achieved through reconstruction activity, and the level of perceived threat within a population. PSOM allows factions to raise and train units, and the power of insurgent and national armies to rise and fall after a few years of simulation game time. Monthly displays of all these measures allow players to determine the rate and magnitude of progress toward achieving their strategic or operational goals.

Use: PSOM represents a broad spectrum of actors and their “forces” in a PSO. Interactions among factions are many-to-many; political allegiances can shift, coalitions evolve or collapse; factions can rise in power from being marginal spoilers to de facto national governments, or fail and be destroyed. PSOM uses HTL (Human in The Loop) to represent the leadership of major factions. An “intelligent Red”, for example, demonstrates the activity of “obstructionists to the peace process”. These can range from organized criminals, through incited disorder, warlords and militias and “traditional” insurgency, to the in-theatre effects of a “globalized insurgency”. These agents all have aims, characteristics, motivations and capabilities that can be portrayed in the game system. An expanded set of “target options” gives the spoiler player a realistic set of alternatives between opposing armed forces, infrastructure, or civilian populations. Military operations are represented by a range of irregular and regular units in both semi-symmetric and asymmetric combat. The value of intelligence-led and multi-sided HUMINT (Human Intelligence) can be shown alongside technical ISR capabilities. The importance of good intelligence is shown in a complex physical and human environment. The impact of collateral damage and deterrence is shown alongside a more traditional understanding of kinetic effects. Using a novel combat system based on current and historical data, PSOM combines the effects of a large number of low-level land combat operations. Political interference and logistics constraints restrict such operations for insurgents and intervention forces, while difficult trade-offs between rules of engagement, force protection, and force effectiveness can force players to make realistic compromises.

Its known strength: Completely driven by editable scenario and data files, PSOM provides an easy visual interface of the qualitative and quantitative results of the simulation. It includes military, information, economic, migration, criminality, deterrence, recruitment, and rioting models. It provides a platform for learning negotiation strategies and the whole-of-government approach to SSTR through war gaming exercises. Also allows for high-level game inputs representing the real-world non-predicable events that drive irregular situations such as environmental or political decisions.

Its known limitations: High-level, low-resolution model that may not capture real-world complexity and provide detailed answers.

STRATMAS

Vision: Strategic Management System (STRATMAS) is an interactive war-gaming environment and software development project that provides a modelling and data capture framework, and visual and formal synthetic representation of failing states (Christensson & Woodcock, 2004). It supports the generation of intervention plans and models interactions of such plans with the failing state. STRATMAS works in conjunction with a staff support tool called Cupol that guides a large distributed planning staff through the operational procedure steps of "effects based planning". When a user issues an order through Cupol, it is sent to STRATMAS for simulation, optimization and gaming.

Development: users can build an operational theatre by assigning values to 25 indicators that describe a failing state. These indicators cover themes such politics, governance, economics, society, quality of life and environment encoded as raster with around 10-20 km spatial resolution. National media reports and their effects on the population of the failing state can also be provided to make scenarios more plausible (Christensson et al. 2005). STRATMAS represents population dynamics using a combination of spatial systems dynamics and cellular automata: variables in each cell evolve and interact with courses of action provided by users according to predefined, constant equations. While the underlying STRATMAS model represents disaggregated political actors explicitly, with Blue representing friendly entities and Red adversary entities, and requires that time- and spatially-encoded orders, it does not have an explicit C2 structure as CLARION and DIAMOND.

STRATMAS works as a client-server software and can be reached from any client in buildings connected to the internal LAN where the STRATMAS game engine is installed. Current STRATMAS development focuses on elaborating the high-level architecture with a run-time infrastructure, standardized software library. This enables multiple country simulations and data exchange among models other than the default systems dynamics engine STRATMAS is shipped with.

Use: STRATMAS has been tested in two different theatres: Afghanistan, and Iraq.

STRATMAS was used to study post-conflict reconstruction for Afghanistan in January 2003. STRATMAS supported Exercise Iraq Future 2005 in April 2004.

STRATMAS supported in March 2006 a major NATO Partnership for Peace Exercise on Afghanistan at the US Joint Forces Command, Norfolk, Virginia.

STRATMAS was initially developed by an international team under the joint sponsorship of the U.S. Joint Staff and the Swedish National Defence College; currently however it is solely supported by the Swedish Armed Forces. STRATMAS clones are still developed by the Swedish National Defence College as Game Environment for Command and Control Operations (GECCO) and serve as inspiration for systems dynamics models that simulate the establishment of public order and safety in a post-conflict reconstruction or phase IV operations (Richardson et al. 2004). STRATMAS has the following strengths: configurable planning procedure with support for distributed analysis, planning, simulation and optimization; users perceive short training period to be productive; fast and responsive analysis time, quick and fast interactive analysis change, try, modify input and run analysis in less than a couple of minutes to broaden a viewer's understanding. Its known weaknesses: not HLA compatible and does not support regional or continent based analysis, planning, and optimization.

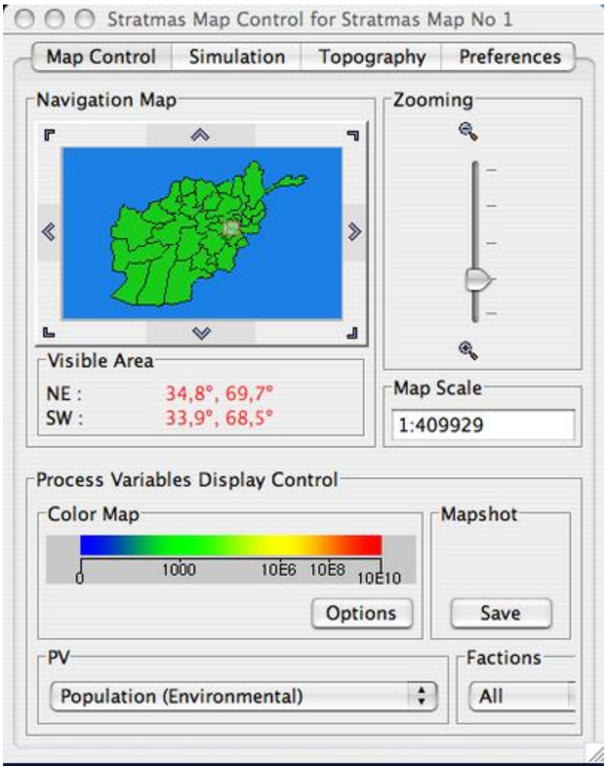


Fig.27 - STRATMAS map control screenshot (https://www.kth.se/profile/andersc/page/stratmas?l=en)

PAX

Vision: PAX is a multi-agent model of Peace Support Operations (PSO), developed by EADS Dornier, initiated and funded by the Bundeswehr and assisted by the Operations Research Division of the Bundeswehr Centre for Analyses and Studies (Lampe et al. 2007). A team led by EADS Dornier and sponsored by the Bundeswehr started to develop a PAX prototype after the Bundeswehr realized that attrition-based models previously used were not able to meet its needs to model human behavioural aspects, civilian populations and non-combat focus that are critical in peacekeeping operations. In order to achieve a measure of plausibility, experts in social psychology, systems theory, operations research and military advisors who are proficient in peace support operations have provided input to and participated in the development of PAX. Therefore, representation of civilian behaviour sets PAX apart from other multi-agent models of conflict. In particular, PAX represents how main psychological drivers such as anger, need and fear may be influenced by external factors from the environment such as soldiers' actions and other civilians' behaviours. PAX behaviour patterns and interactions are based on empirical knowledge about the evolution and de-escalation of aggression (Mosler & Schwarz 2005).

Development: areas in PAX scenario maps at the meter-scale resolution grid may be defined in such a way as to limit the movement of agents across different fields:

• Normal cells can be traversed by all agents. They may further be fine grained with areas of influence that range from 0 to 3, represented as light-grey, light-blue, pink and light-green accordingly.

• Built-up cells serve as refuge for civilian agents who are frightened or have already received a supply package or cast a vote.

• Barrier cells cannot be traversed by any agent and can be regarded as natural or man-made obstacles, such as a river, barbed wire or fence. Communication however, may still happen across the barrier. Currently PAX houses three types of agents: Civilian, Soldier and Supply Vehicle:

• Civilian: the initial states of a civilian may be set up to be representative of a typical character through the parameters such as "Fear", "Readiness for aggression", "Anger" and "Need". Civilians belong to different groups; therefore, PAX can model groups with different goals and leadership and study group behaviours and interactions among groups.

• Soldier: the role of Soldier can be set to Normal, Admission Control or Reserve. A Soldier's actions are governed by a specific rule set that remains constant during the run.

• Supply Vehicle: the first scenario for which PAX was developed dealt with food distribution in peacekeeping operations. The scenario implicitly included a supply vehicle and a squad to guard and distribute food packages. No movement associated with the supply vehicle. However, PAX was later used to study a polling scenario, so the supply vehicle may now be defined as either of the two service agent types: the supply vehicle or the polling station.

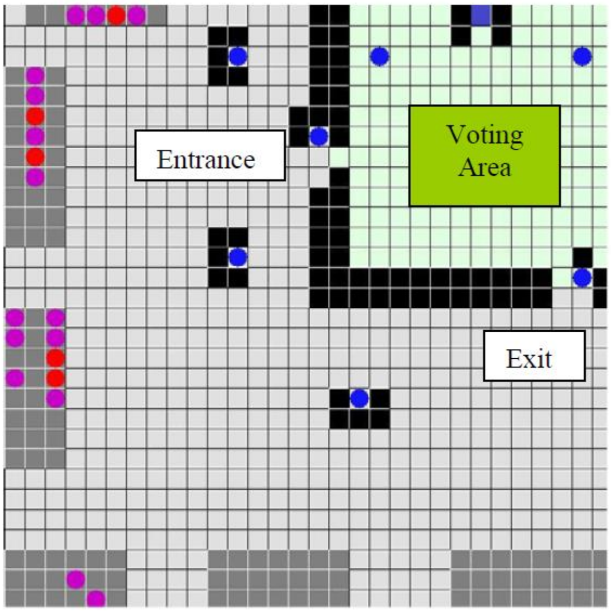


Fig. 28 - PAX Election Polling Place configuration (Curtis, 2005).

Use: PAX can measure success of peacekeeping operations strategies using measures of effectiveness like:

1. The overall escalation during the operation measured for example, by the acts of aggression performed against civilians;
2. Amount of help provided measured for example, by the number of distributed food packages;
3. Possible long-term effects of an operation measured for example, by the number of civilians willing to pick up arms or civilian grievances caused by the operation.

PAX can be used to study a variety of complex scenarios, for example, the impact of martial law on Iraqi towns or the problem of setting up a refugee camp and operating it. Example: each refugee is assigned a place in a tent that can house 10 refugees; the civilians in the camp belong to the same ethnic group but different subgroups; use of force in the camp is governed by the force provider's law and rules of engagement; the military distributes food to one representative per tent at specified and well-known distribution times in a dedicated food distribution area, which is separated from the rest of the camp by a barbwire fence. The performance of PAX on scenarios like this has been validated experimentally (Johnson et al. 2009). PAX enjoys a 3D extension for scenario replay. Data farming capabilities are also available.

Its known strength and limitations: as war-game, PAX has strong potential as a high-level staff and leader training tool and as a planning aid for course of action development. Within the confines of this study, the model proved limited in its ability to model changes in force capabilities. Due to its limited ability to model uncertainties in irregular warfare without the human-in-the-loop, or give multiple potential outcomes, further development and analysis is required before the model is used for large scale analysis (Marlin, 2009).

Attitude change and diffusion models

Vision: In a number of research projects, Wander Jager and his colleagues at the University of Groningen build models of how attitudes and opinions spread through a population, contending that such processes are crucial in understanding the rise and fall of interest groups, dynamics of political change and shifts in population preferences (Jager & Amblard, 2004). In such models, the authors forgo the substance of people's opinions, and does not model how people argue for shifting their opinions or spreading certain attitudes and how they process such mental processes; instead, biased diffusion or social cascade processes are applied to various classes of social opinions, regardless of their substance. Jager justifies this assumption by arguing that the quality of people's reasoning may determine the extent to which they are being persuaded by others; people often respond quite simply by favouring positions close to their own, rejecting more distant positions according to some pre-existing latent positions or following the crowed in voicing their opinions. While Jager's recent work advocates the predictive power of such an approach in marketing and product innovation settings (Delre et al. 2010), most of his models can be applied to conflict settings.

Development: in a very popular piece, Jager and Amblard (2004) implemented a social networked version of the social judgment theory originally formulated by Sherif and Hovland (1961), to explain how and why individuals change their position after being confronted with another position. Agents in this model are endowed with a vector of attitudes, but are not purposive: they do not seek to maximize their influence or form coalitions, but simply passively broadcast their positions. The basic dynamics of the model describes a change of a person's attitude that depends on the position of the persuasive message that he receives. If the advocated attitudinal position is close to the initial position of the receiver, this position is said to fall within the receiver's latitude of acceptance and the receiver is likely to accept it as his own. This is called the assimilation effect. If the advocated position is distant to the initial position of the receiver, it is said to fall within the receiver's latitude of rejection and the receiver is likely to shift away from advocated positions in his latitude of rejection. This is called the contrast effect. If the advocated position falls outside the receiver's latitude of acceptance, but is not distant enough to fall into his latitude of rejection, it falls within the receiver's latitude of non-commitment, and the receiver will not shift its initial position. This set of behavioural rules suffices to produce complex dynamics. Jager has also addressed the issue of data necessary to calibrate such models, in particular the data necessary to recover the social networks that underlie the attitude diffusion process. Collecting complete empirical network data is rather difficult, because it does not contain all influential relations. So Peter and Jager (2010) proposed a methodology to construct simulated networks on the basis of survey data that are easier to collect. These networks are later re-optimized with regard to common network properties such that they conform both to established theories and the constraints derived from the survey data. Such simulated networks are expected to provide a more valid representation of real social networks used in multi-agent modelling of attitude change.

Use: the social judgment theory that underlies Jager's work is tested extensively in small laboratory settings, but methodological limitations have hindered empirical work on how assimilation and contrast effects shape attitude change at the population.

Humanitarian Assistance and Disaster Relief (HADR) models

Vision: this section reviews two similar models sponsored by US Air Force Office of Scientific Research (AFOSR), and the European Office of Aerospace Research and Development (EOARD). The first model results from a direct contract to a Czech university, and it is documented by Pechoucek, Marik and Barta (2003) at the Agent Technology Centre of the Czech Technical University in Prague. The second model, described in Smirnov et al. (2005), is developed by modellers from the Russian Academy of Sciences in Saint Petersburg.

Both models are motivated by similar goals. They aim to support planning humanitarian assistance and relief operations (HADR) in the short run, up to a month. However, the difference is that the Czech model accounts for a large number of hardly collaborating and vaguely linked nongovernmental organizations, whereas the Russian model assumes a fully collaborative environment. This means that the Russian model focuses on engineering optimality, while the Czech model needs to find an alternative knowledge sharing solution first then tackle the coalition formation problem. Both models ultimately propose information sharing and planning procedures for HADR and test them on very abstract and fictitious scenarios. The Czech model addresses a hypothetical humanitarian scenario in which an island suffers from a natural disaster while several fictitious foreign governments are ready to help; the Russian effort models the health service logistics of deploying mobile hospital configurations in the Sudanese Plain.

Development: The very special nature of the HADR domain in which individual organizations may eventually agree to collaborate, but are very often reluctant to share their knowledge and resources, the Czech modellers tried to reduce the complexity of the problem by splitting the community of agents into ex ante alliances formed exogenously to the model. They combine classical negotiation mechanisms with acquaintance models and social knowledge techniques in order to reduce the communication traffic and to keep some of the agents' knowledge private. In particular, they represent the following classes of entities:

• Resource Agents (R-agents) represent the in-place resources that are inevitable for delivering humanitarian aid, such as roads and airports. Unlike the H-agents defined below, the R-agents are passive and do not initiate any kind of humanitarian effort.

• In-need Agents (In-agents) represent the centres of conflict such as cities and villages that call for help.

• Humanitarian Agents (H-agents) represent humanitarian agencies participating in a HADR effort. Like the R-agents, the H-agents contribute to humanitarian aid missions, so they may be regarded as a subclass of R-agents.

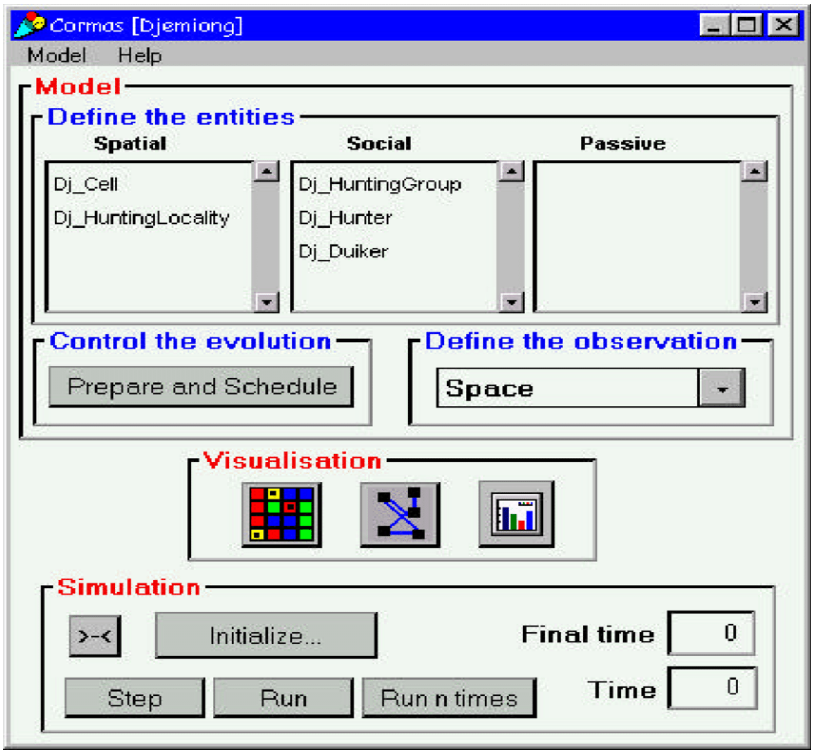
However, the H-agents are proactive and they can initiate coalition formation processes. Each H-agent has some private and public knowledge and aims to share information with other H-agents and to form resource-sharing coalitions with them to fulfil the needs of In-agents in his neighbourhoods. The computational and communication complexities of forming such coalitions depend on the amount of background and processed information each agent possesses about other agents and on the sophistication of the agents' capability to reason about other agents' resources, plans and intentions. One interesting feature in this model is the notion of strong and weak information disclosures. Weak disclosure corresponds to straightforward information sharing. If an agent loses some type of private or semi-private knowledge in the strong sense, it does so as a side-effect of some proactive step such as sending a request to other agents or making a move. This means that some H-agents can influence other H-agents or alliances of H-agents without explicit communications, avoiding situations in which direct attempts at communicating is rejected outright. The resulting distributed communication and planning procedure is called CPlanT and yields feasible distributed plans without breaking alliance constraints for any entity.

The Russian model is called Knowledge Sharing Networks (KSNet) and assumes a network-centric environment, potentially without any hierarchies, but with all entities willing to collaborate with each other. KSNet constructs for each agent (a) a perception of the elements of the current situation, and (b) comprehension of the current situation by applying formalisms borrowed from Endsley's situation awareness model (Endsley, 1995). It then uses the off-the-shelf planning algorithm ILOG to develop schedules and plans for each agent. Both models represent the needs of the underlying population that require relief as static requirement sets; none of the models accounts for strategic interactions among the segments of the population, among relief organizations and between organizations and populations segments. KSNet and derivatives for operational decision support are still being developed.

Use: AFOSR, CERDEC and ONR programs that sponsored this research were focused on developing distributed solutions to C2 and survivability of communications networks. The use of particular HADR scenarios does not seem to have been the main focus for program managers. None of the technology has transitioned.

CORMAS (companion modelling)

Vision: this section describes a family of models, a software framework and a model building and application methodology developed by the *Centre de Cooperation International en Recherché Agronomique pour le Developement* (CIRAD). CIRAD is particularly interested in models for integrated renewable resource management (IRRM) and integrated natural resource management (INRM) in development contexts. The IRRM effort at CIRAD focuses on studying, educating and building awareness of (a) biological, climate and hydrological interdependencies, and their dynamics on different spatial and temporal scales; (b) technical and socioeconomic factors involved in IRRM decision and policy making, and (c) feasibility and usefulness of specific negotiation processes for establishing collective rules for local IRRM. The key innovation of CIRAD in addressing (a), (b) and (c) was to initiate the problem solving process by building and honing the companion modelling approach.



Fig, 29 – CORMAS main interface (https://www.researchgate.net/figure/The-CORMAS-main-interface_fig2_230802218)

Development: the key principle that informs companion modelling is developing simulation models that integrate various stakeholders' points of view and using such models within the context of the stakeholders' platform for collective learning (Barreteau et al. 2003; Becu et al. 2007). In this problem solving approach, stakeholders participate in the model building enterprise in order to improve their relevance to the overall effort by having their concerns addressed and their interests included in the model. Companion modelling is an iterative or cyclic process made up of three repeating stages:

• Collecting input data and defining output measures: field investigations, literature search and observations supply information and help modellers to generate explicit hypotheses or scenarios for modelling;

• Modelling Conversion of existing knowledge into a formal tool to be used as a simulator;

• Experimentation Simulations, conducted according to an experimental protocol either on a computer or through a role playing game (RPG), challenge the former understanding of the system and identify key questions for novel investigations in the field.

To support the companion modelling process, CIRAD has developed a multi-agent simulation software suite called Common-pool Resources and Multi Agent Systems (CORMAS). CORMAS represents interactions among individuals using renewable resources on a small scale on a Small Talk visual programming environment in which the modellers fast-prototype a model by (I) implementing classes from their UML class diagram, including specifying behavioural and communication rules of agents; (II) writing initialization and scheduling of simulation scenarios, including loading layers with GIS data on the environment, and (III) specifying means to visualize simulation scenario. A typical scenario for CORMAS simulations includes a few villages and a dozen decision making agents who interact over an extended period of many years. CORMAS assists modellers with detailed representation of agricultural and ecological cycles.

Use: the companion modelling process helps stakeholders to play the game and understand the model. More precisely, companion modelling helps stakeholders to grasp the differences between the model and reality and the assumptions that drive these differences, especially their own interests, desirable end-states and policies that they have declared they will pursue. Stakeholders follow multi-agent simulations on the computer and propose scenarios to be assessed and discussed through further simulation runs. Companion modelling is self-validating: stakeholders examine the individual behaviours of agents, their interactions, and the properties of the system emerging from their interactions, and can propose modifications to these behaviour or interactions. In companion modelling, stakeholders modify their own behaviours; therefore, the predictions of the underlying mulita-gent model are fulfilled in the future.

Sample works developed using CORMAS include the following: Mathevet et al. (2007) have used CORMAS to develop a tool in the context of a LIFE-Nature European Programme that aims to improve reed bed management for the conservation of a vulnerable heron, the Eurasian Bittern. This multi-agent model simulates the impacts of reed bed management resulting from decisions made by farmers, reed harvesters, hunters and naturalists. CORMAS has also been used to model rural credit practices and land rights management in village-level simulations of Thai and Vietnamese villages. In Africa, CORMAS has been used to create a multi-agent model of land use and irrigation management in Senegal (Barreteau et al. 2004) and a multi-agent simulation of hunting wild meat in a village in eastern Cameroon (Bousquet et al. 2002). Dray et al. (2008) have developed a slightly different and more abstract CORMAS model to study drug markets in Melbourne.

Population data availability has turned out to be the key obstacle to applying social sciences in influence activities and outreach (IA&O). While IA&O requires sound knowledge of offline and online properties and behaviours of the target population, proper population data is rarely available and access to the target population is often limited. Yet, bits and pieces of data can be found in national and international organizations samples and surveys, and online data can be scrapped from websites and social media or tracked via commercial entities. Disconnected data on offline and online population characteristics and behaviours can be fused into descriptions of target populations amenable to support IA&O. The fusion process is called population synthesis and results in an all-life synthetic population. All-life synthetic populations maintain delicate balance between the level of detail necessary to support information and influence campaigns and sparseness that makes it possible to replicate the data product across multiple countries, and refresh it at low cost and with a small footprint. The knowledge of the population under study is often unavailable in a host of critical applications such as IA&O analytics, military planning, critical incident management or public policy. A synthetic population addresses this type of data shortage: it is an image of a real-world population built by algorithms that fuse partial input data on the real-world population into an output dataset called the synthetic population. The output contains all the information in inputs and more information than any single input. In general, population synthesis creates a data product of a higher quality than any single source used in creating it, for example, an aerial image of a neighbourhood where the houses are overlaid with dots for individuals labelled by race, and income. The idea is to empower IA&O not by more data, but the right kind of information made available at the right moment: before the next crisis, conflict or war occurs. Data products should therefore be created by a data fusion process that combines data sources on individuals' offline and online lives and unfolds in three steps. The first step of the process is to synthetize the offline population for the year of the last national census and update it using a microsimulation. The second step imputes average daily online time for every individual by a classifier that accounts for a person's age, gender, location, educational attainment and labour market activity. The third step fuses the offline population with online activities. A microsimulation of an individual's browsing produces online activity traces, including locations and access devices, session durations, visited websites and associated motivations. Methods that estimate every unit of a population are called population synthesis algorithms and the resulting estimates are called synthetic populations. Common methods of population synthesis rely on a maximum likelihood estimator called iterated proportional fitting, or a sampling technique called combinatorial optimization (Müller 2010). Network growth algorithms (Mussavi Rizi et al. 2012) and micro simulation (Latek et al. 2013) can also be used when micro samples are not available or data is sparse. Synthetic populations are routinely used in agricultural (O'Donoghue 2013), transportation (Guo & Bhat 2013), business (Hermes and Poulsen 2012) and public health (Barrett et al. 2011).

T-REX: A Hybrid Warfare Simulator

Vision: in order to better understand the implications of Hybrid Warfare and its nature and the potential for applying M&S, during NMSG ET-043 Meeting in Rome and along the NATO CAX Forum 2016, preliminary examples of capabilities were basically demonstrated. The Simulation Team developed a new NCF (Non-

Conventional Framework) addressing Hybrid Warfare by using its IA-CGF (Intelligent Agents Computer Generated Forces); the simulator was presented at NMSG ET-043 (February 2016, Rome) and exhibited at NATO CAX Forum 2016, as an example of the potential use of M&S in this sector.

This Simulator is named T-REX (Threat network simulation for REactive eXperience) and it is a MS2G (Modelling, interoperable Simulation & Serious Game) that combines Complex System Modelling and intuitive Serious Game framework. T-REX is a stochastic discrete event, virtual interoperable simulation, able to perform fast time runs in order to evaluate vulnerability reduction as well as risk assessment respect hybrid warfare scenarios. T-REX includes meta-models dedicated to reproduce specific aspects (e.g. communications) that could be used for fast simulation or substituted by federating details models made by specific tools (example OPNET network simulator, by reproducing in details the communication protocols and hardware devices).

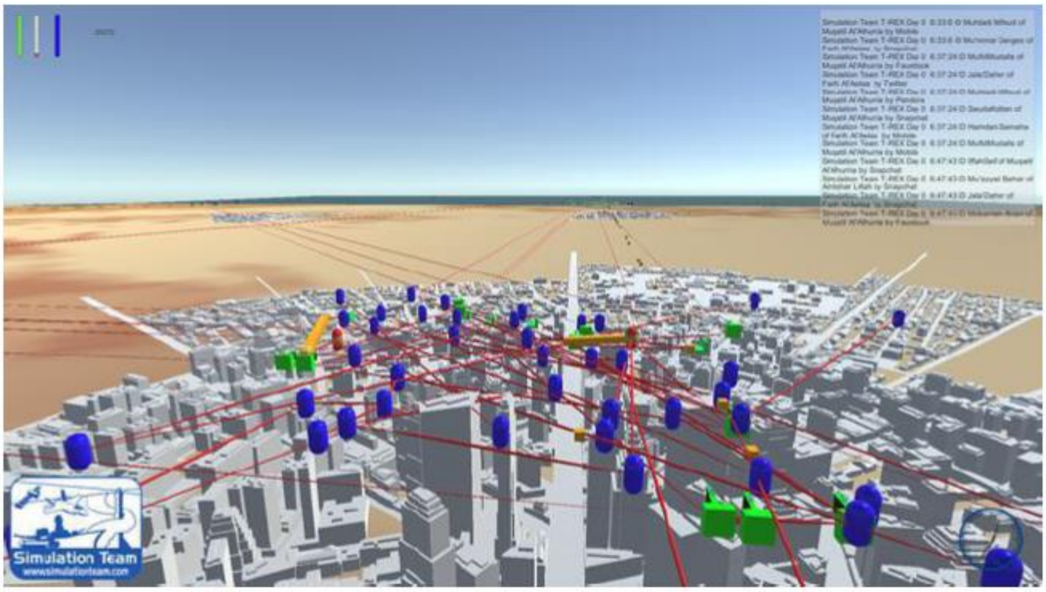


Fig. 29 T-Rex: A Hybrid Warfare Simulator

Development: The approach proposed by Simulation Team reproduces the context on multiple layers including people (single individuals and/or families) and interest groups (e.g. one political party, a leader, an industrial association, a religious group, a social class), each one with its own social network and mutual relationships. In addition to the socio cultural and economic layers the simulator includes other layers; one is the Entity & Units Layer where military assets operate and influence population behaviours. In addition, T-REX includes technological layers (e.g. power grip, communication networks). One very critical element of this simulation is represented by the layer reproducing the Cyberspace by modelling the ICT (Information and communications technology) and related interconnections. Cyberspace in T-REX is constituted by nodes and links, characterized among the others, by Integrity, Availability and Confidentiality Levels that evolve dynamically for each element; by this approach it becomes possible to conduct actions on cyber elements (e.g. an IP Address, a PC) and see the effects on the operational layer as well as on the social one. For the reasons above, T-REX is able to reproduce Hybrid Warfare in the cyber domain and to be federated with other elements to evaluate the impacts of actions and decisions. T-REX is used to simulate urban, as well as extra urban contexts over multiple domains including land, air, sea, space and cyberspace; indeed T-REX elements are driven by the IA-CGF that act and react based on their perception about the situation awareness and the boundary conditions; by the use of IA-CGF and different T-REX meta-models guarantee the possibility to consider media communications and to evaluate different assets by experimenting virtually alternative decisions in terms of COAs (Courses of Actions) within an Hybrid Warfare Scenario.

The native HLA (High Level Architecture) structure of T-REX simulator guarantees interoperability and allows to keep this environment open for being federated with other simulators; indeed T-REX has been already tested integrated with JESSI (Joint Environment for Serious Games, Simulation and Interoperability), a virtual interoperable environment with many different models to simulate complex heterogeneous networks including traditional and autonomous platforms (e.g. Unmanned Aerial Vehicle, drones, Unmanned Ground Vehicles, Underwater Unmanned Vehicles as well as vessels, aircrafts, land vehicles, missiles, etc.) that operates over a joint scenario (i.e. air, land, sea, space, cyberspace) .

Use: T-REX demonstration during ET-043 workshop (Hybrid Warfare M&S Exploratory Team) has been performed on February 2016 in Rome, Italy, in a complex scenario reproducing threat networks, suspects and population over a small region and their behaviour driven by IA-CGF based on their status, human behaviour modifiers (HBM) and their specific life cycle. The scenario included a medium size city, four small towns within a desert area facing the sea; on the coast near the major town it was simulated a small port with an oil terminal, a tank farm, a desalination facility with multiple units, a power plant and the related security system (e.g. perimeter sensors/cameras/defence, ICT Network). The demonstration integrated also different UAV (Unmanned Autonomous Vehicles) in ISR (Intelligence, Surveillance, and Reconnaissance) respect threat network. The cyber layer of T-REX in this case included computers, laptops and mobile IoT (Internet of Things) as well as firewalls and procedures. The threat network was composed by terrorist agents able to adopt different operative modes such as “sleeping”, “stand by”, “planning action”, “preparing action”, “executing action” on different layers. In the simulation, the attack is based on diffusion of a sleeper virus, installed over a flash memory, infecting and affecting integrity just on specific systems. The goal of the cyber attacker is to have the virus compromising just one specific server (i.e. Port Security Server), accessing it from an infected computer through a remote supervisor access. The demonstration allowed to reproduce the diffusion of the virus and the actions of the threat networks, as well as the opportunities to capture the spill of information by the Joint Intelligence, Surveillance and Reconnaissance (JISR), as well the evaluation of the impact of the attack to study vulnerability reduction, impact on population and effectiveness of offensive and defensive actions over the different layers.

T-REX simulator represent an example of the potential of using advanced intelligent agents and multi-layer modelling in reproducing Hybrid Warfare scenarios, even to evaluate and test hypothesis and assumptions related to vague or uncertain factors. Hybrid Warfare (HW) is a complex context where the use of simulation and intelligent agents is probably the most promising investigation methodology. Despite this context is pretty new and requires tailored solutions, it is necessary to review researches and models developed along the years that could be useful in this framework, as for the task performed during the work of ET 43.

During the TREX demonstration at NATO MS COE and CAX forum, emerged the importance to be able to conduct vast experimentation and define the criteria to create the scenario based on the available information and on the different hypotheses; by this approach it will become possible to evaluate symptoms and to study impacts of actions and reactions as well as to analyse their consequences respect population and social-economic-political tissue.

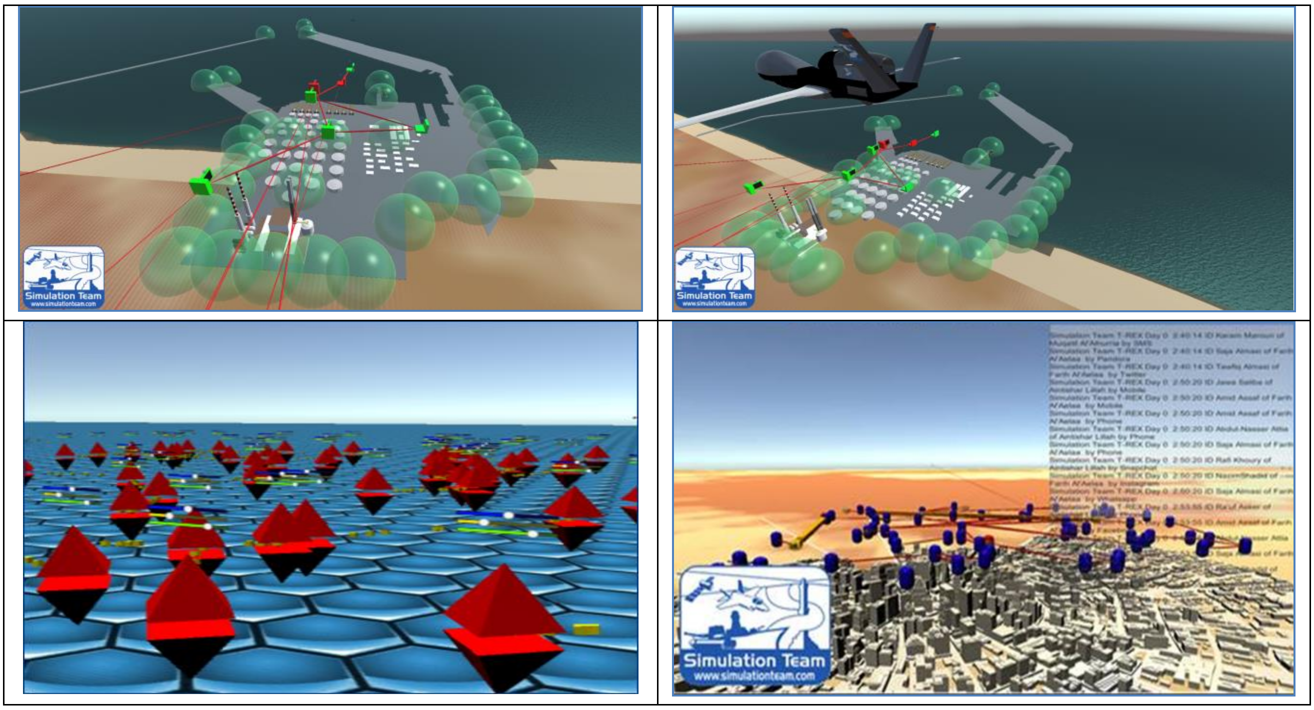


Figure 30 T-REX Model reproducing different Layers, Modelling Population and Cyberspace as well as mutual interference over a complex threat scenario

SIMCJOH

Vision: SIMCJOH project was devoted to carry out R&D activities with the aim of understanding at which extent interoperable simulators can be used (in a multi-coalition context) by a Commander and his/her Staff to address and solve specific problems where human factors are relevant. Modelling & Simulation makes possible recreating complex scenarios and carrying out what-if analyses with the aim of evaluating the effectiveness of several alternatives (Course of Actions, COAs) and therefore prepares the Commander and his Staff to face unusual situations.

The SIMCJOH objectives are to study and develop new simulation models in order to support the decision makers in Joint and Multi- Coalitions scenarios, considering a strong involvement of Human Factors (either of friendly forces, opposing forces or neutral agents/population) effecting military Course of Actions (COAs) with a particular focus on issues of refugees and civilians in a theatre of military operations. The initiative get benefits from innovative researches in population and Human Behaviour Modelling.

Figure 31 – SIMCJOCH screenshot. A Peacekeeping Patrol has been encircled by rather hostile crowd, which demands the surrender of weapons and vehicles.

Primary SIMCJOH Goal is to provide a Commander with the capability to investigate the consequences of different decisions in terms of Collateral Damages in terms of PMESII second effects. Time constraint and uncertainty are the main the critical elements that the Commander has to handle in order to succeed in the simulation run. Secondary SIMCJOH Goals are:

- To investigate impact of N2M2C2 and technology on Strategic Decision Making in Multi-Coalition Environments;
- Interoperability issues (different C2 Maturity Levels, etc.) effecting Joint & Combined Coalitions' Cohesion;
- To demonstrate technological capability to combine Strategic Decision Making Models with other simulation Models for further developments in terms of CAX, Educational Programs and/or future Operational Planning and On-Line Decision Making.

Development: SIMCJOH is a Stochastic High Level Architecture Simulator able to operate in different modes. It applies Innovative M&S (Modelling and Simulation) methodologies combining Intelligent Agents and Artificial Intelligence techniques. SIMCJOH benefits of existing models, tools and simulators developed among the partners:

- CAPRICORN (Cimic And Planning Research In Complex Operational Realistic Network) Description: HLA Federation for DIME/PMESII Simulation over Geographic Regions;
- DYTACCO (Dynamic Targeting Collateral Damages and Consequences) Description: Simulator of Dynamic Targeting Collateral Effects
- GESI (GEfechts-SImulation System) Description: simulator of environment with simulated forces and groups, military and civil forces, NGOs, population and events.
- IA-CGF (Intelligent Agents Computer Generated Forces) Family. Description: HLA Intelligent Agents reproducing HBM in a wide Spectrum of Applications
- INDASTRIA Description: Simulation Model considering Regional Economic/Social Crisis;
- NCS (Network Communication Simulator) Description: Discrete Events Simulator for operational network asset, analysis, Communication and Networking, testing.
- PANOPEA (Piracy Asymmetric Naval Operation Patterns modelling for Education & Analysis) Description: Simulator of Multiple Coalition and Nation involved in Anti-Piracy;
- PIOVRA (Poly-functional Intelligent Operational Virtual Reality Agents) Description: HLA Federation for HBM Simulating within Urban Area
- PSYSOPS (Psychological and cultural Simulation Of Population) Description:
- HBM Simulation within Urban Area considering Individual, Social and Cultural Factors
- SGA (Scenario Generator and Animator) Description: subset of M&S Control Room, in conjunction with NCS allows to add a real-time simulation of specific assets and recreate networking and communications.

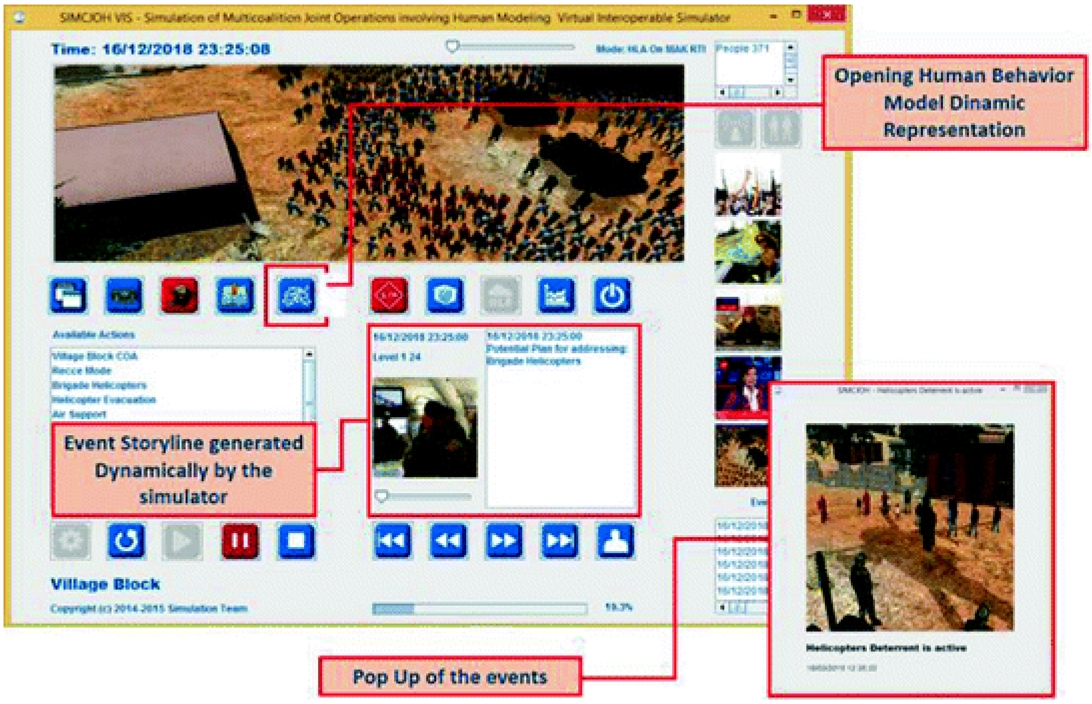


Figure 32 - SIMCJOH for Simulation based Military Training (Springer, 2017)

Use: SIMCJOH Demonstration was carried out at the MS COE by presenting all the different models as well as the whole SIMCJOH Federation; indeed, SIMCJOH could operate also in stand-alone mode as well as on a local network of laptops. Demonstration consisted in presenting the evolution of MEL/MIL respect a Village Block in the fictional country named “Eblanon”, roughly corresponding to a Middle East realistic Scenario.

The Stand Alone Mode allows Commanders to evaluate impact of different COAs and possible evolution of the scenario. The users benefit the combination of dynamically generated reports by Virtual Assistant, tactical situation and virtual representation. In HLA Mode is demonstrated the capability to federate in High Level Architecture the different Models providing a complete and flexible approach to address Strategic Decision in Multi Coalition Joint Operations involving Human Modelling where the Commander have to face criticalities. The demonstration is interactive and it is possible to change decisions and check consequence over dynamically generated stochastic scenarios. The SIMCJOH project reached several goals such as the involvement of military experts evolved along the project, in a kind of virtuous loop where users disseminate these results in the military community becoming good promoters of the Project and allowing to find and involve new experts from different offices. A positive result is the birth a multidisciplinary team of military users with an increasing understanding of potential uses of innovative M&S techniques (i.e. IA-CGF) out of traditional and established areas of application of simulators; indeed, this project has provided an important contribution to disseminate the potential of using use M&S to face complex Military and Homeland Security issues.

1.5.3 M&S Requirements for modelling Hybrid Warfare

Before introducing the subject of the current paragraph, it is necessary to highlight that most of the activities (exercise on top) carried on within NATO have a security classification, and in accordance with that, the employed hardware and software simulation have to stick with such security requirements; this because NATO it is made up of a political and a military body, both requiring confidentiality when handling and exchanging information (figure 33 below).

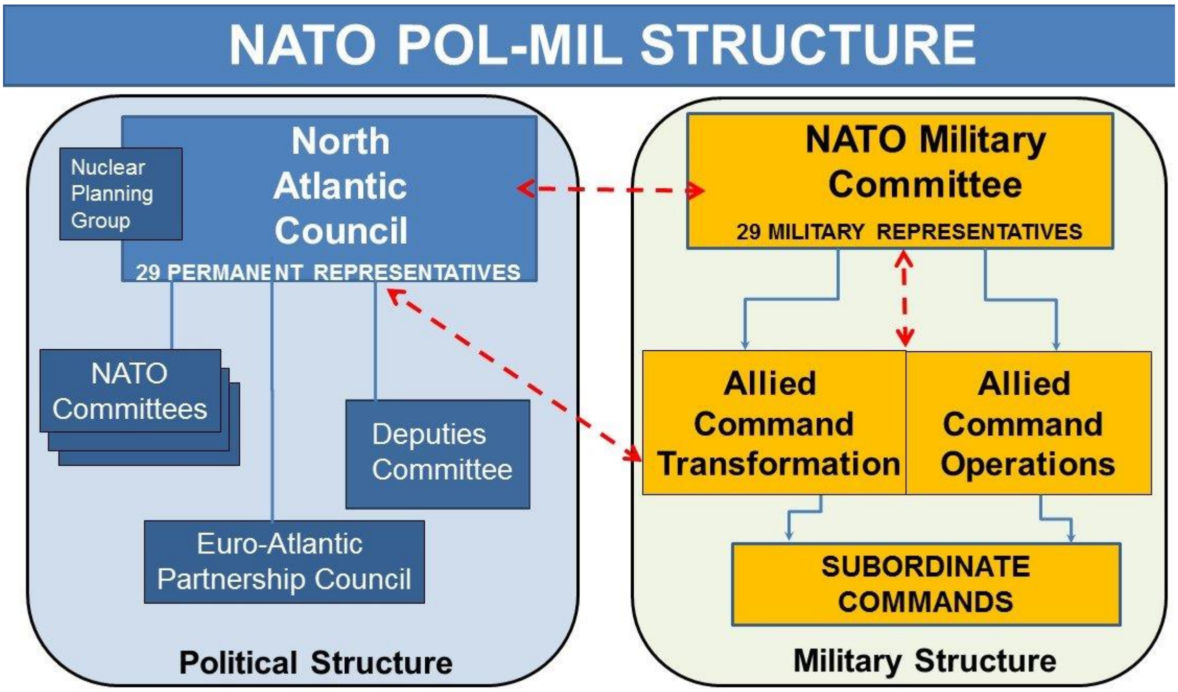


Fig. 33 – NATO Politic/Military Structure

The foundations for establishing the M&S Requirements for Hybrid Warfare (HW) have been identified by considering the above described researches in terms of state of art, survey and experimental demonstrations. Considering the complex nature of Hybrid Warfare, it is self-evident why M&S is the proper Science able to provide a strategic advantage. So, in order to counter Hybrid Threats at the Alliance strategic level, the following NATO processes need M&S support:

- NATO Defence Planning Process (NDPP);
- Crises Response Planning;
- Concept Development;
- Doctrine Development;
- Capability Package Management.

In addition to these aspects, the following real life processes need M&S support for hybrid environments:

- Strategic Level Awareness;
- Decision Making Process at North Atlantic Council Level (NAC).

For the support listed above, the following types of models and simulation need to be provided:

- Conceptual model
- Meta models
- Discrete event simulations
- Real-time stochastic (human in loop) simulations
- Agent based dynamic simulation

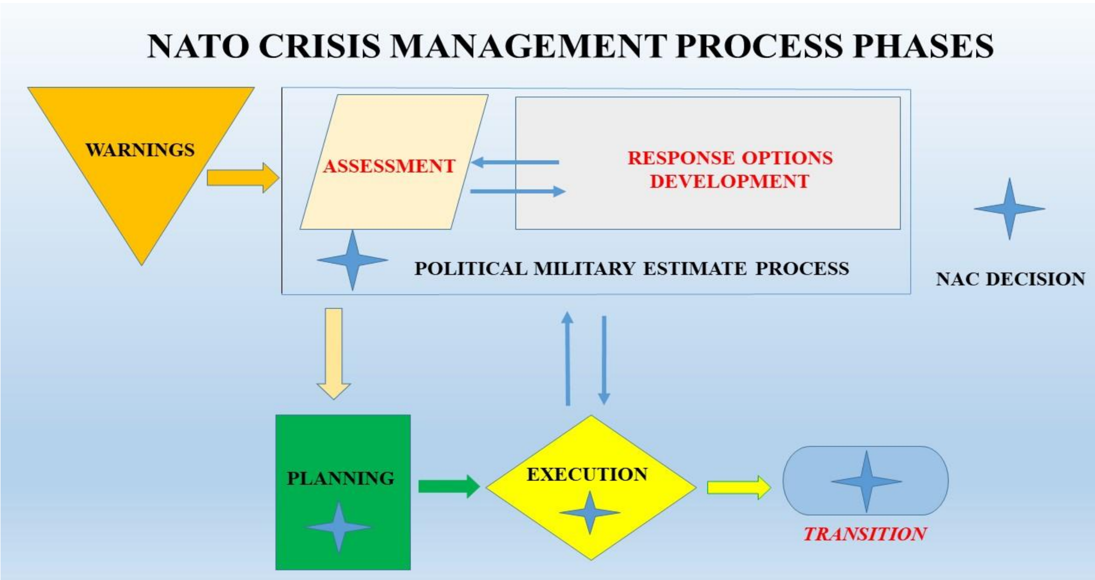


Fig. 34 - NATO Crisis Management process

Below the strategic politic level there are the operational and tactical military levels, in which M&S applications results very promising in addressing requirements in terms of:

- ✓ Individual Training;
- ✓ Collective Staff Training;
- ✓ Concept Development & Experimentation;
- ✓ Decision Making Support
- ✓ Exercises;
- ✓ War-games.

Actually, in terms of training, exercise and war-games, the M factor inside PMESII environment is already well addressed, while other parameters do not enjoy the same level of granularity as the military factor already achieved. This again calls for the necessity to take in consideration in our survey around MSHE the non-military factors of Hybrid Warfare. So, as example, the STRAT and POL simulation, which should adopt the Serious Game paradigm, has to implement the outcomes of the NATO Defence Planning Process (NDPP), and vice-versa. The NDPP needs itself a type of dedicated simulation, which must adopt a dynamic paradigm based on the necessity to maintain the memory of prior inputs (i.e. decisions adopted in the past could orient the future ones), internal variables (i.e. the attitude of each government respect the situation on-going); for this reasons, it is evident that static models and simulations, where relationships do not change over time, are not adequate. The necessity to maintain memory of the past sticks very well with the paradigm of discrete event simulation, where event occurs at particular moment of time and determine a change of state in the system (Bruzzone et al. 2016a).

In conclusion, when modelling Hybrid Warfare environment, to some pre-defined set of variables should be granted the possibility to change stochastically, within an assigned set of individual probability; to summarize, the simulation system should be dynamic, discrete event, stochastic. For these reasons, M&S requirements must be aimed at developing models and tools which tackle with the complexity of the hybrid environment. Such simulations of hybrid environments have to run in “isolation mode”, thus leading to the creation of a tool, able to operate for the purpose of individual and collective training, exercise, war-games and real time support to decision making processes.

In the next paragraphs, models to describe the mechanics of hybrid warfare environments will be presented.

1.6 A CONCEPTUAL MODEL FOR HYBRID ENVIRONMENTS

In this paragraph it is described a conceptual model for hybrid environments (CMHE), developed by Bruzzone, Cayirci, Longo and Guinnarson (2016), which formalizes the salient findings of the NATO ET 43. The model can be visualized as in the figure below.

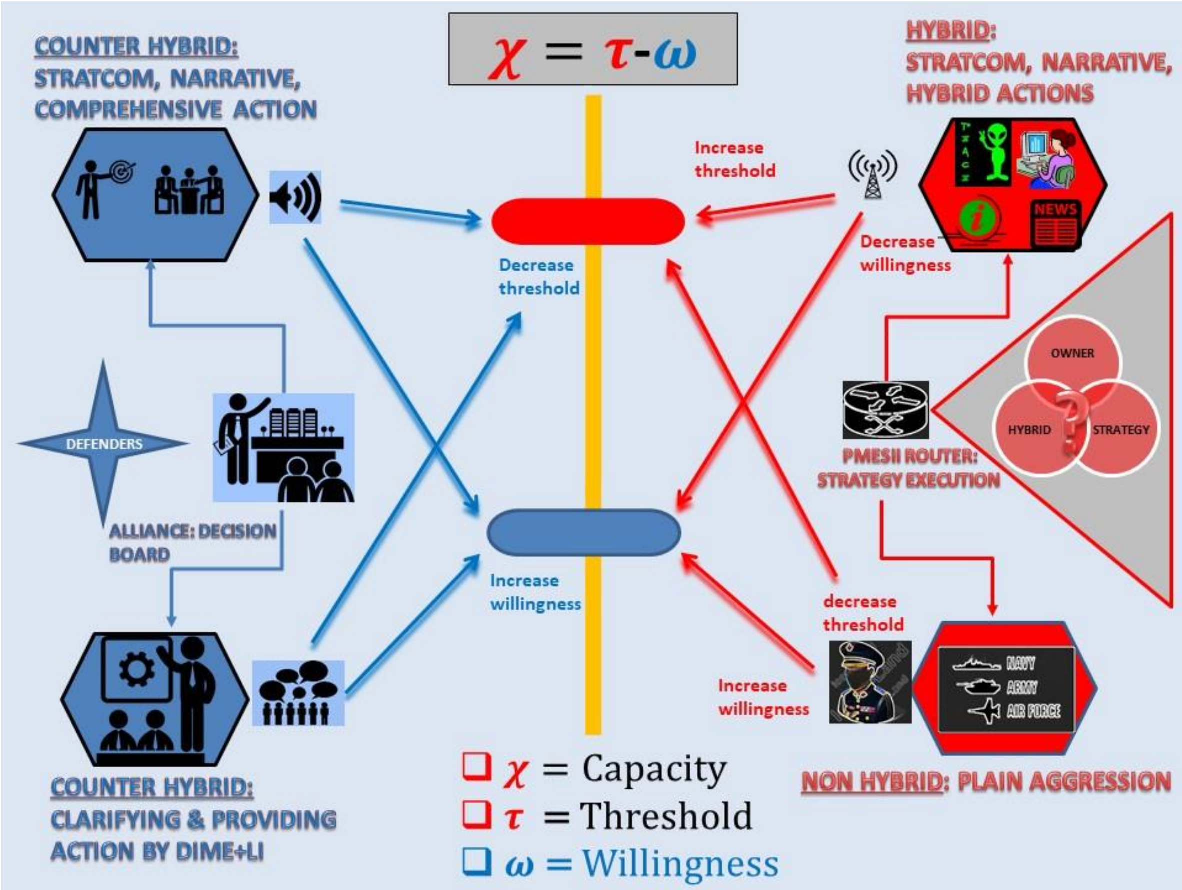


Fig. 35 - Hybrid Warfare explained in terms of Capacity, Threshold, Willingness

As it is showed above, a hybrid strategy is an offensive strategy (right side of the scheme). There are two key values related to the community/nation under attack, namely the *Willingness* and the *Threshold*. The willingness is the level of desire and stamina by the targeted community to engage with the offender. It also implies the support by the international community to the defendant. When the willingness is over the threshold, the targeted community approves tackling with the offender, even an armed conflict, after which the hybrid environment may become a theatre of operations, unless the offender backs off. Of course, after this point, the offenders' homeland may also become a theatre of operations, and hence, the conflict is not a proxy war for the offender anymore. In both cases, the hybrid environment witnesses the prevalence of the military operations.

Those concepts expressed above, in particular threshold, match very well with the current UN Chapter VII provisions, titled" Action with respect to threats to the peace, breaches of the peace, and acts of aggression". With regard to this subject, Karski and Mielniczek (2018), in recalling the legal discourse around hybrid warfare in international law, wrote that "*it is technically possible to wage hybrid warfare without an armed attack triggering the right of self-defence. This does not mean that the states being subject to such actions are defence-less, but rather that such dangers require the so-called 'flexible responsiveness'. In case one method merely constitutes a breach of non-intervention principle, it is possible to employ reprisals. Moreover, even if there are doubts as to whether certain actions reach the threshold of coercion, the retaliatory measures can be justified as retaliations. Especially in case of states too weak as to employ reprisals or retaliations effectively deterring the perpetrator, the idea would be to call allies to apply collective retaliations or reprisals".* Elaborating on the legal issues of Hybrid Threats, the Hybrid Centre of Excellence in its December 2017 Strategic Analysis Report (author Tiina Ferm, available at https://www.hybridcoe.fi/publication-tags/strategic-analysis/page/2/), quoted that *"The legal analysis of hybrid threats involves open questions and uncertainties due to the lack of agreed definitions and the state's practice in responding to hybrid threats".*

Therefore, for the defender it is necessary to identify univocally the offender and the related vectors he is manipulating: STRATCOM, Hybrid and non-Hybrid actions (Cayrci, Bruzzone et al. 2016). From its side the offender, the owner of the strategy, aims to keep the threshold as high as possible, while managing the willingness as low as possible. Vague environment, denial and all sort of perception management are the main tools for this (Bachmann & Gunneriusson, 2015). Strategic communications (STRATCOM) is a key both for the defence and the offence in hybrid environments. Apart from STRATCOM, the offender can take hybrid actions which can be denied, and may have to take also non-hybrid actions from time to time. Of course, non-hybrid actions increase the willingness and decrease the threshold.

The defendant aims completely the opposite, i.e., decrease the threshold and increase the willingness. The main reason for this is that the capacity of the offender depends on the difference between the threshold and the willingness. For this, the defendant needs to clarify and prove what the reality is. All the components of diplomatic, informational, military, economic, financial, law enforcement and intelligence (DIMEFIL) domains should be used to achieve that. The aim is to stabilize the alliance/nation under hybrid attack and to gain the international and legitimate support for eliminating the hybrid threats. Therefore, comprehensive approach and STRATCOM are the main tools for the defendant; for the attacker the main tools are his narrative, the power he can project over DIMEFIL, and the exploitation of potential weakness of the defender such as political, ethnical and religious divisions. In Figure 31, the results of the actions are shown as "increase or decrease threshold/willingness". However, there is a well the option for the defender of being passive (i.e., no action is taken); if the defendant is passive and takes no comprehensive action or does not have a proper STRATCOM narrative, the willingness decreases and the threshold increases, so favouring the attacker.

1.6.1 Relation between Capacity, Threshold and Willingness

The capacity χ of the opponent (aggressor) to continue with a hybrid strategy depends on the *threshold* τ and the *willingness* ω. This is given in Equation 1:

$$\chi = \tau - \omega \quad (1)$$

When $\chi \leq 0$, it is expected that *the aggressor backs off or an armed conflict starts*. The aggressor struggles to maintain the capacity χ over zero (i.e., $\chi > 0$), until he reaches the desired level of destabilization of the targeted nation/community, creating the environment to reach its geopolitical and strategic objectives (END STATE).

Threshold is built around four parameters:

- the normalization **ν** of the current level of instability (i.e., the defendant is getting used to the situation);
- STRATCOM by the opponent ***so***;
- STRATCOM by the defendant ***sd;***

- the power **pΣ** of the defendant in all DIMEFIL domains: ***pδ*** (diplomatic), ***pι*** (informational), ***pφ*** (military), ***pε*** (economic), ***pλ*** (law enforcement), ***pσ*** (intelligence) as given in Equations 2 and 3.

The weight ***μ*** of each DIMEFIL domains in overall power **pΣ** of the defendant may be different from each other. In these equations, *so*, *sd* and pΣ are real numbers between 0 and 1 (i.e., $so \in \Re$, $sd \in \Re$, $p\Sigma \in \Re$ and $0 \leq so \leq 1$, $0 \leq sd \leq 1$, $0 \leq p\Sigma \leq 1$).

$$p_\Sigma = \mu_\delta p_\delta + \mu_\iota p_\iota + \mu_\phi p_\phi + \mu_\varepsilon p_\varepsilon + \mu_\lambda p_\lambda + \mu_\sigma p_\sigma \qquad (2)$$

where $\mu_\delta + \mu_\iota + \mu_\phi + \mu_\varepsilon + \mu_\lambda + \mu_\sigma = 1$

$$\tau = (v\, s_o) - (p_\Sigma\, s_d) \qquad (3)$$

STRATCOM is everything that can pass the messages according to the narrative; this includes not only verbal or written messages, but also all actions taken. Social computing is a critical media to disseminate the STRATCOM narrative by the defendant, as well as the disinformation by the opponent.

In Equation 4 and 5, the normalization parameter ν depends on the history, the types of the opponent's actions and their frequencies:

$$v = \sqrt[d^h]{\prod_{c=1}^{m_i} \left(\prod_{k=1}^{n} (1 - R_{ck\alpha}) \right)^{t_i/n}} \qquad (4)$$

$$v_i = \frac{R_\rho}{t} v_{i-1} + \left(1 - \frac{R_\rho}{t}\right) v \qquad (5)$$

It may change from community to community how well and how long the history is remembered. We call this parameter as the memory parameter ρ. The number of events (i.e., hybrid and non-hybrid actions taken by the opponent) *n* in the last period *i* that the normalization parameter is evaluated for, and the length *ti* of the time interval between the last normalization evaluation and current time give the frequency (*n/t*) of events. Please note that the unit (i.e., months, weeks or days) for time intervals does not make an impact on the model. However, there is at least one event in every time interval and therefore the length of time intervals is not a fixed value.

It is also an important parameter how disturbing α an action is. This parameter represents the difficulty, which needs categorization of events in space and character. In the model, the number of categories *m* is not a fixed value and may change in every evaluation period *i* as the length of time intervals do.

The frequency (*n/t*) is typically controlled by the designer of the hybrid strategy. On the other hand, the memory parameter ρ and the degree of difficulty α change from community to community, and there is an uncertainty associated with them. It is not easy to treat this uncertainty in aleatory domain at least for the time being. Still we refer them as random variables, i.e. $\rho{:}\Omega\rightarrow\Re+$ and $\alpha{:}\Omega\rightarrow\Re+$, where $R\rho$ $(\Omega, \Im\rho, P\rho)$ and $R\alpha$ $(\Omega, \Im\alpha, P\alpha)$ are the related random processes, Ω is the set of positive real numbers between 0 and 1 and including 0 and 1 (i.e., $0 \leq \Omega \leq 1$), $\Im\rho$ is the set of values for how much the past influences the perception about the current situation (i.e., the weight of the past on the current perception), $\Im\alpha$ is the set of values for how difficult to normalize an event, $P\rho$ and $P\alpha$ are the probability density functions and statistics that fits best to the defendant.

The other important parameters for calculating the normalization factor ν are ethnical and religious divisions *d* (i.e., the number of ethnical and religious groups) and how much these divisions discriminate or tolerate (or even to support the opponent) *h* each other. The division parameter *d* is a positive integer greater or equal to one (i.e., $d \in Z$ and $d \geq 1$). The discrimination parameter *h* is a real number greater than zero and less than or equal to two ($h \in \Re$ and $0 < h \leq 2$).

Please note that there is at least one event in each category c (i.e., for $\forall$c, mi $\geq$ 1). Otherwise the category does not exist. Therefore, ν is a real number between 0 and 1 (i.e., $\nu \in \Re$ and $0 \leq \nu \leq 1$).

1.6.2 Parameters affecting the Willingness

The following parameters affect the willingness: STRATCOM by the opponent *so*, STRATCOM by the defendant *sd*, the power $p\Sigma$ of the defendant in all DIMEFIL to clarify and communicate the facts, the effectiveness of the comprehensive actions *ad* by the defendant, hybrid *aon* and non-hybrid *aol* actions by the opponent as shown in Equations 6-8, where *ad*, *aol* and *aon* are real numbers between 0 and 1 (i.e., *ad*∈ℜ, *aol*∈ℜ, aon∈ℜ and 0≤ *ad* ≤*1*, 0≤ *aol* ≤*1*, 0≤ aon ≤*1*). The division *d* and discrimination *h* parameters already explained in the previous subsection.

A part *nl* of the number of events *n* are non-hybrid, and the other part *nn* are hybrid actions. Therefore, *n*=*nl*+*nn*.

$$a_i = \prod_{c=1}^{m_i} \left(\prod_{k=1}^{n_l} (a_{ol})_{ck}{}^{1/1+(a_d)_{ck}} \right)^{t_i/n} \tag{6}$$

$$a_r = \prod_{c=1}^{m_i} \left(\prod_{k=1}^{n_n} (a_{on})_{ck}{}^{1+(a_d)_{ck}} \right)^{n/t_i} \tag{7}$$

$$\omega = \frac{p_\Sigma s_d\, a_i - (1 - p_\Sigma)\, s_o\, a_r}{d^h} \tag{8}$$

1.6.3 Tests on Model Behaviour

Through Monte Carlo Simulation, the authors observed how the model behaves when independent parameters change. In the experiments, random numbers had been generated for the memory parameter ρ and the degree of difficulty α according to normal distribution with various mean values. The sensitivity of the threshold τ, the willingness ω and the capacity χ against the changes in the other parameters of the CMHE was examined. The results are provided and analysed below.

In Figure 36, the sensitivity against the changes in frequency (n/t) of the actions by the opponent is depicted and the values assigned to the other parameters during these tests are given in the caption of the same Figure. As expected, the community gets used to the hybrid environment as the frequency of events increase, and therefore the threshold increases, which also means better capacity for the opponent. As the frequency gets higher, its effect on the threshold gets lower. The sensitivity of the willingness is less against the frequency comparing to the threshold.

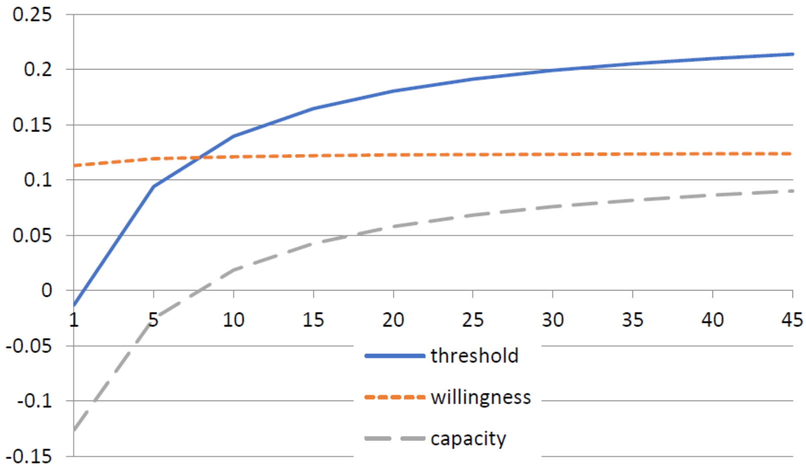


Fig 36 : The sensitivity against frequency (n/t) when α=0.5, P_Σ=0.5, s_o=0.5, s_d=0.5, a_d=0.5, a_{ol}=0.5, a_{on}=0.5, d=2, h=1.

In Figures 37 and 38, the relations between the capacity and STRATCOM are shown. Both the threshold and the willingness are affected by the effectiveness of the STRATCOM by the defendant. Better defendant STRATCOM results in an increase in the willingness and a decrease in the threshold and the capacity. An opposite relation is observed between the threshold and the STRATCOM by the opponent as expected. There is another difference between the effects of STRATCOM by the opponent and the defendant, which is the sensitivity of the willingness against the changes in STRATCOM by the opponent is much less comparing to the STRATCOM by the defendant.

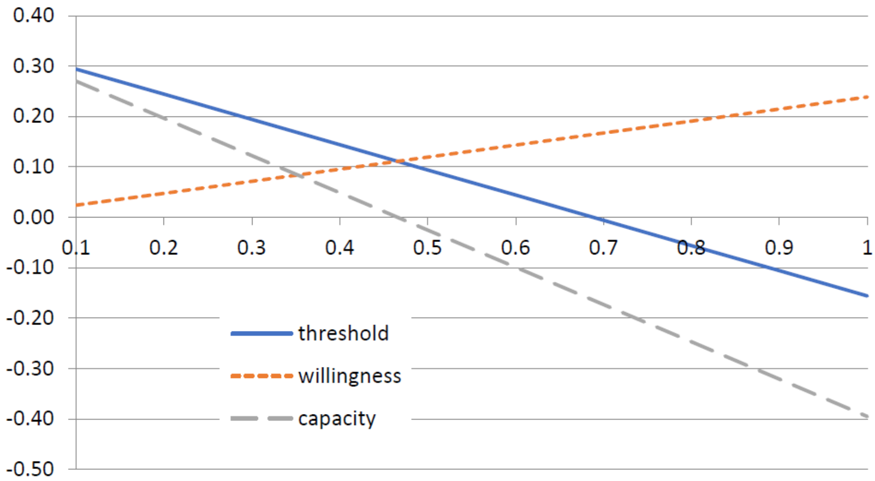


Fig 37 The sensitivity against STRATCOM by the defendant (s_d) when α=0.5, P_Σ=0.5, n/t=10, s_o=0.5, a_d=0.5, a_{ol}=0.5, a_{on}=0.5, d=2, h=1.

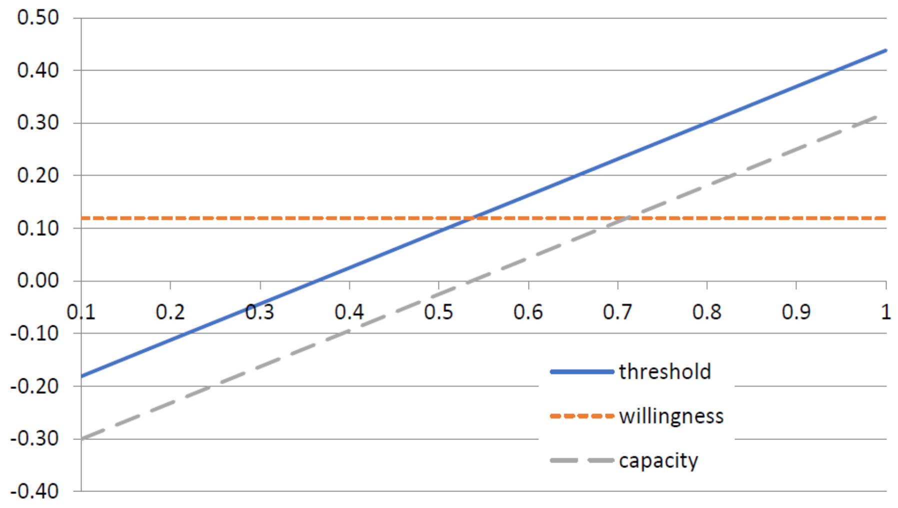


Fig 38 The sensitivity against STRATCOM by the opponent (s_o) when $\alpha=0.5$, $P_\Sigma=0.5$, $n/t=10$, $s_d=0.5$, $a_d=0.5$, $a_{ol}=0.5$, $a_{on}=0.5$, $d=2$, $h=1$.

In Figure 39, the results from the tests for the discrimination parameter h are illustrated. How much the divisions in a community discriminate each other is an important weakness that can be exploited easily by the opponent. This is clearly observable: when the discrimination is higher, the willingness of the community to tackle with the opponent is lower. On the other hand, the higher the discrimination is, the higher the threshold and the higher the capacity of the opponent become.

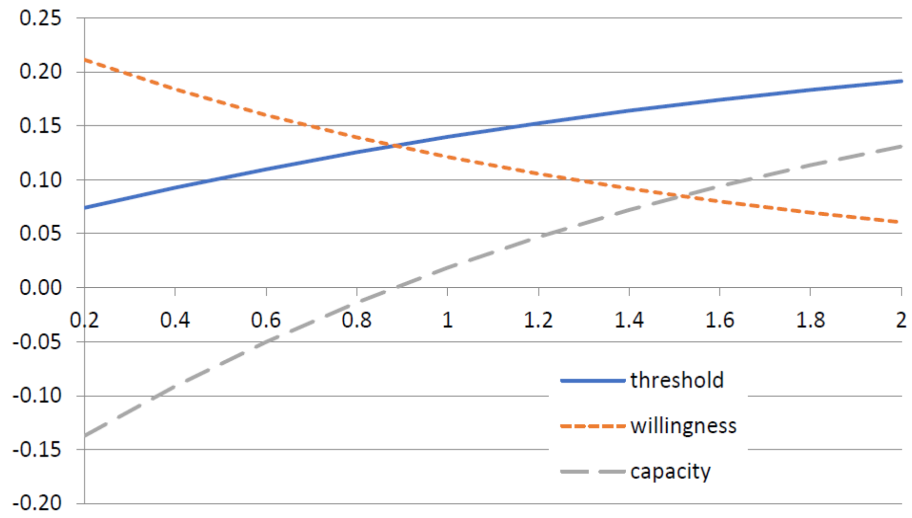


Fig 39 The sensitivity against discrimination (h) when $\alpha=0.5$, $P_\Sigma=0.5$, $n/t=15$, $s_o=0.5$, $s_d=0.5$, $a_d=0.5$, $a_{ol}=0.5$, $a_{on}=0.5$, $d=2$.

As shown in Figure 40, as the actions by the opponent gets more difficult (i.e., more disturbing) for the defendant, the threshold decreases, because those events are more difficult to be normalized (i.e., more difficult to get used to). The willingness of the community changes in positive direction but much less comparing to the threshold.

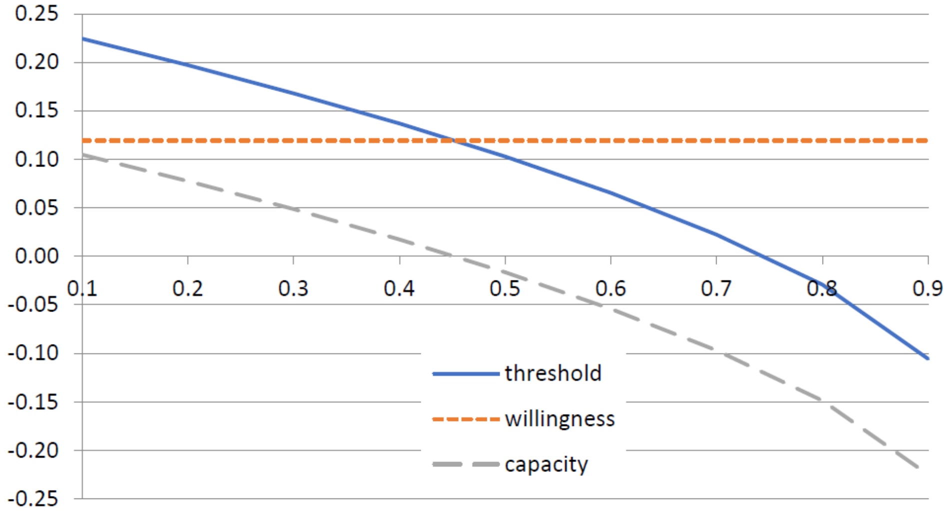


Fig 40 The sensitivity against the difficulty (α) of the opponent actions when P_Σ=0.5, n/t=10, s_o=0.5, s_d=0.5, a_d=0.5, a_{ol}=0.5, a_{on}=0.5, d=2, h=1.

The last experiment was about the effectiveness of the comprehensive actions by the defendant. They do not change the threshold but the willingness, which gets better as the comprehensive actions by the defendant becomes more effective. However, the effectiveness of the comprehensive actions is not much if they are not supported by a consistent STRATCOM narrative (Fig. 41, below).

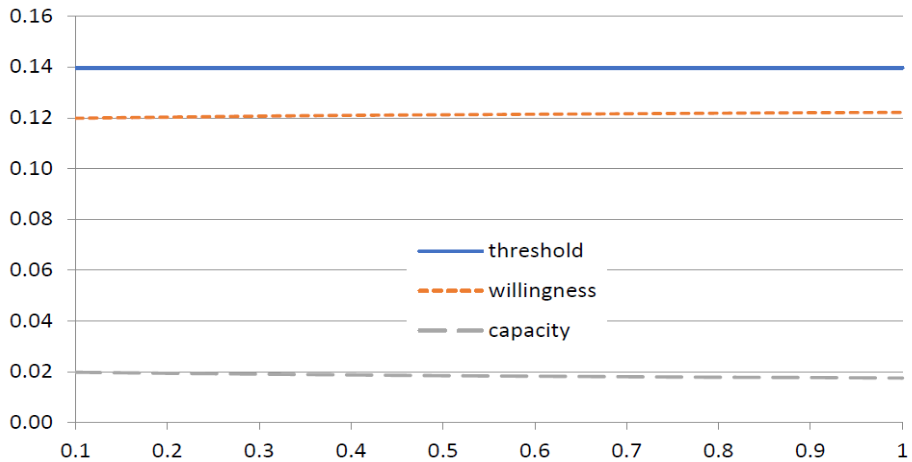


Fig 41 : The sensitivity against comprehensive actions (a_d) of the opponent actions when α=0.5, P_Σ=0.5, n/t=10, s_o=0.5, s_d=0.5, a_{ol}=0.5, a_{on}=0.5, d=2, h=1.

1.6.4 Further Inquiries

In a hybrid warfare, the adversary uses all available means, very often from the black/covert side, in order to exploit the vulnerabilities of the defendant and to destabilize it by creating ambiguity, denial and disabling the defendant in time sensitive decision making process.

The attacker, i.e. the owner of the Hybrid Strategy, manages two parameters against the defender, threshold and willingness. In doing so he tries to meet its objectives without an armed conflict, and as well without a major change in its diplomatic and economic relations toward the targeted state. Eventually, he gets engaged in an armed conflict at the minimum possible level, however without triggering the reaction of the international community; this because he is aware that the willingness is also strongly related to the international community's desire to support the defendant. When the willingness is over the threshold, the strict hybrid part of warfare is over one way or the other, i.e., either the adversary backs off or has to face an armed conflict with the defendant. Therefore, the attacker does its best to raise the threshold as much as possible without losing the control on the willingness. As such, the Attacker can modulate the friction through the time by adjusting the level of the threshold, according to its political will. However, it is hard to foresee how long the Attacker can keep up with such strategy, that over time can result in the defender getting acquainted/developing narrative and physical countermeasures, or arriving to the depletion of the resources of the Attacker himself. In order to succeed, a Hybrid Strategy must be developed according to an operational plan that phases - over a pre-defined time span - together all the different means and tactics such as: cyber-attacks, disinformation, limited military actions, economic sanctions, diplomatic threats, espionage, subversion, assassination of named individuals, etc., most of them under the common denominator which is the denial of responsibility.

Further issues to be taken into account when modelling the system is that, even a positive narrative through STRATCOM, will find the adversity of the public opinion in case of staggering losses (being either human or materiel) suffered by the enemy (Bruzzone et al. 2019a); on such regard, the defender in any case will meet a limit in its legitimate right to counter the aggression. On the other hand, if the attacker is a Rogue State, or it has an Authoritarian form of Government, this means

that it can rely on a unified and strictly vertical chain of command (which is both his strength and his weakness), while the defender(s), even though initially fragmented and supposed to work within the UN chapter VII and (in some cases) NATO article 5 rules, (only) once it realizes the threat can effectively cope with it.
The above consideration however brings inside the model the time perspective as the critical factor for both (Bruzzone et al. 2019b; Di Bella, 2019), because:

a) the attacker should expect to run more and more out of time, so he has to accelerate the speed of confrontation when needed, and should be able as well to abruptly decelerate at the threshold, if he wants to avoid to wake up the "dormant";
b) the defender increases its strength through time (unless he chose for whatever reason to stay inactive), by realizing he is under threat and so building up his willingness, eventually overcoming the odds ratio vs the attacker.

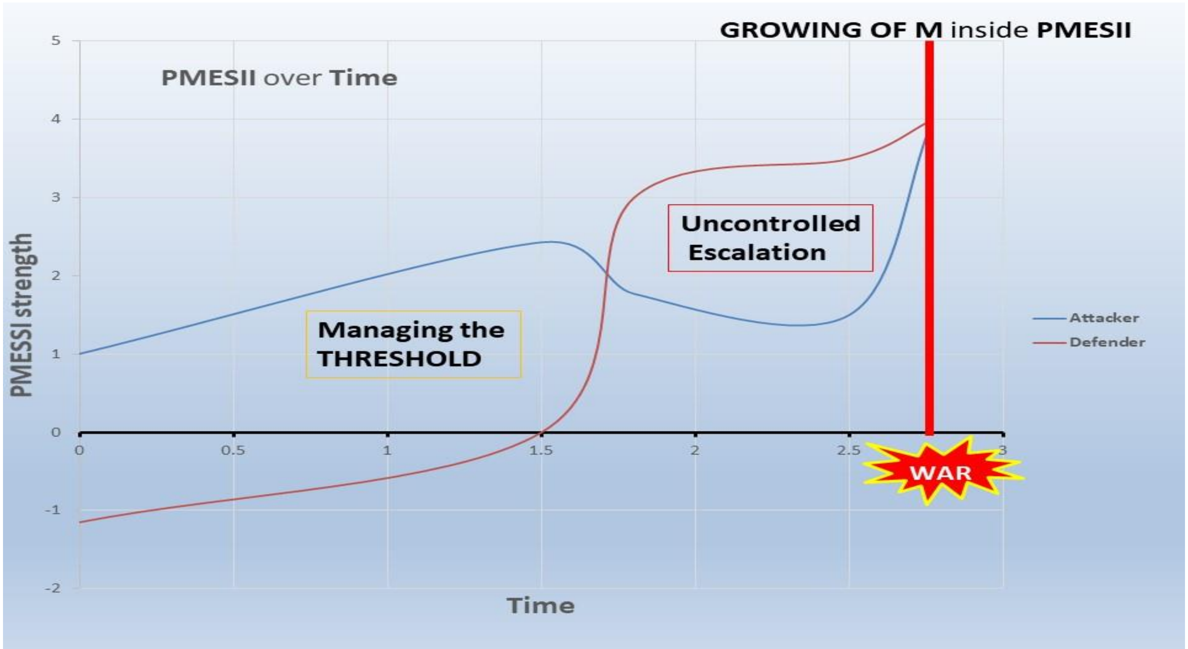


Fig. 42 - Graph of PMESII over time: past the threshold, the risk of an all-out military conflict rises.

In a few words, the model describes very well the hybrid conflict, and stops at the eve of either the attacker steps back from the aggression or the transformation into a so called “conventional” one. Further elaborating on this, it is possible to speculate, as it is depicted in the figure 42, about the risk that the Attacker lose control of the system, i.e. not being able to decelerate quickly enough when the defender is rapidly building up his response, with both victims of an unpredictable escalation into an all – out conflict (unfortunately, as already seen, example in the crisis of July-August 1914 that ignited WW I). The point to highlight here is that, even though no-one wants a full-scale war (a moot point in itself), it can still occur in the event of political and military misunderstanding and miscalculation (Roberts, 2019; Bruzzone et al. 2019b); so, it is could result very difficult or impossible to control the DIMEFIL/PMESII vectors/status once the threshold is passed.

1.7 HYBRID WARFARE: THE ORDINARY DIMENSION OF FUTURE CONFLICTS?

Switching from a NATO perspective to a European contest, we meet the description of Hybrid Threats given by the European Union in 2018: *“Hybrid threats combine conventional and unconventional, military and non-military activities that can be used in a coordinated manner by state or non-state actors to achieve specific political objectives. Hybrid campaigns are multidimensional, combining coercive and subversive measures, using both conventional and unconventional tools and tactics. They are designed to be difficult to detect or attribute. These threats target critical vulnerabilities and seek to create confusion to hinder swift and effective decision making. Hybrid threats can range from cyberattacks on critical information systems, through the disruption of critical consciously refrains services such as energy supplies or financial services, to the undermining of public trust in government institutions or the deepening of social divisions. As attribution is difficult, these challenges require specific and coordinated measures to counter*. The above description matches very well with the one given by Cayirci, Bruzzone et al. (2016), however it is indeed true that it gives a description of the phenomena, rather than a strict definition (Bekkers et al. 2019).

However, it is necessary to remind that Cayirci, Bruzzone et al. primarily view at any hybrid confrontation as the “black side” of the NATO Comprehensive Approach. The NATO Comprehensive Approach was introduced in the contest of Lisbon Summit of November 2010, where NATO’s new Strategic Concept was

adopted. In particular, it was underlined that lessons learned from NATO operations show that effective crisis management calls for a comprehensive approach involving political, civilian and military instruments; military means, although essential, are not enough on their own to meet the many complex challenges to Euro-Atlantic and international security. Allied leaders agreed at Lisbon to enhance NATO's contribution to a comprehensive approach to crisis management as part of the international community's effort and to improve NATO's ability to contribute to stabilization and reconstruction (NATO Lisbon Summit 2010; NATO AJP, 2017).
Now in the paragraphs below we will examine two interesting contributions which, while they not deviate by large from the findings of the NATO ET 43, however offer interesting insights, proposing the concept that Hybrid is a form of confrontation not new at all, and that Hybrid Threats can build themselves up into a Hybrid War.

1.7.1 Hybrid Threats rather than Hybrid Warfare

Fig. 43 – Little green men and drones (pictures from: Hybrid Threats: The New Normal? publications.tno.nl/publication/34627573/imXFNr/TNO-2019-hybride.pdf)

In their analysis of Hybrid Threats, the authors (Bekkers et al. 2019), avoid the term "Hybrid Warfare" in favour of "Hybrid Threats"; this because according to them it is necessary to maintain a distance with the (traditional) military ways and means to wage war, which are far too limited. Elaborating their perspective, authors have identified in the DIMEL acronym the different instruments of power which are used within the frame of any conflict: Diplomatic, Informational, Military, Economic/Financial and Legal instruments- also referred to as DIMEFIL, whereby the added 'F' stands for Financial and the 'I' for Intelligence; when using DIMEL, these factors are included under respectively the economic or the information instruments. As such, they can be used in multiple dimensions and on multiple levels simultaneously. However, they are all aimed at the same goal and synchronized in order to strengthen each other. This is visualised in the figure below.

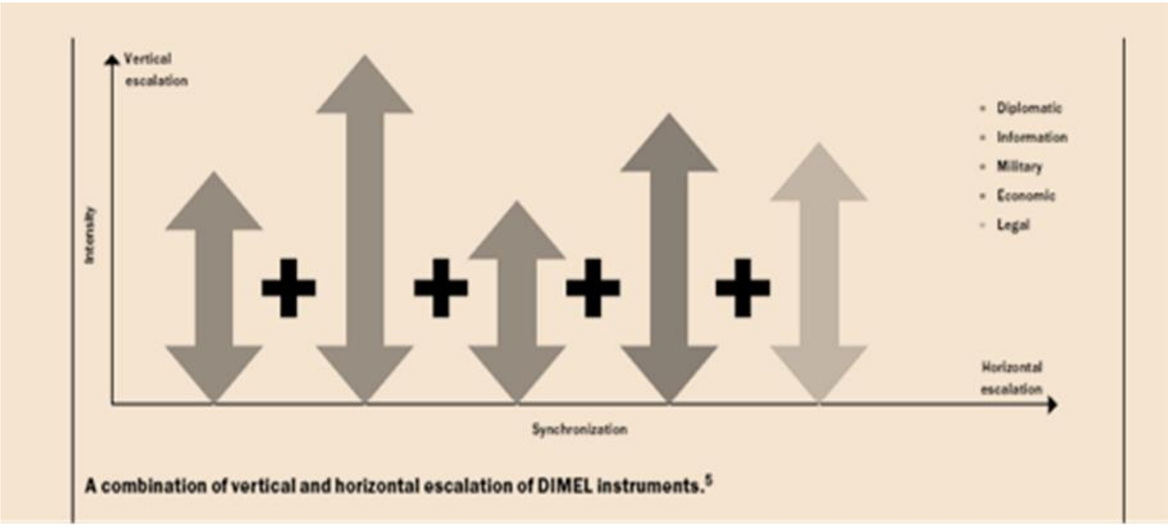


Figure 44 - Variety and intensity in DIMEFIL (Bekkers et al. 2019)

On the horizontal axis we find the different instruments that can be used, and in the vertical axis there are the variety in the intensity of the use of each instrument. So ideally in the process of using hybrid means, an actor can escalate by intensifying the use of a certain instrument (vertical escalation) or escalate by switching to a different instrument (horizontal escalation). Such model of horizontal and vertical escalation seems very promising for the research; however, such new perspectives in order to be exploited necessitates of an analysis about the relation among the different instruments in conjunction with time factor, in order to enquiry about the capacity of the model to represent the real system.

In conclusion, the take away which is offered by the authors is that "*as a concept, the use of hybrid strategies and hybrid tactics to influence or coerce opponents is of all ages. However, continued globalization, the transition to the information age and rising geopolitical tensions have put new emphasis on hybrid hostilities that manifest themselves in a contemporary way*". So, recalling the name of the article, Hybrid is not the New Normal, but rather what is new are the issues posed by

Globalization and technology in the contest of hybrid confrontations, coupled with a diplomatic framework where open aggressions are discouraged because of the provisions of UN Chart and NATO article 5. For such reasons, Western adversaries are acting in ways and through technological capabilities designed to avoid a full-scale conflict (Roberts, 2019), so going Hybrid.

1.7.2 A Causal Loop Model for Hybrid Warfare Modelling

According to Balaban & Mielniczek (2018), the use of Modelling and Simulation (M&S) is aimed at representing past and emerging hybrid conflicts by identifying the factors and deceptive mechanisms leading to the accumulative effects, so preventing, mitigating, and finally winning the confrontation. Authors share the perspective (Murray & Mansour, 2012; Lamb & Stipanovich, 2016; Bekkers et al., 2019) that hybrid conflict is not an entirely new phenomenon, offering a few historical examples. However, hybrid warfare encompasses a wide range of activities, pursued by state as well as non-state actors (and possibly individuals), in order to gain Political, Military, Economic, Social, Information, Infrastructure, Physical environment, and Time (PMESII-PT) advantages - interesting here is to notice that time as been taken into account, introducing it into the PMESII model.
The flow depicted in figure 41 below shows dependencies with a Causal Loop Diagram (CLD), adopting concepts proposed by:

- Thiele (2015): hybrid warfare combines four instruments of power across DIME;
- Pawlak (2015): identification of the transition from a hybrid conflict to a hybrid war as a situation where hybrid threat evolves and intensifies to overt use of conventional force;
- Rácz (2015): there are three phases in a Hybrid Conflict:
  1) preparatory phase: political and operational preparation dimensions;
  2) attack phase: exploding the tensions, ousting the central power from the targeted region, and establishing alternative political power;
  3) stabilization phase: focused on political stabilization of the outcome, separation of the captured territory from the target country, and lasting limitation of the strategic freedom of movement of the attacked country.

- Cirimpei (2016): PMESII battlespace operational variables are used to assess country's vulnerabilities to a potential hybrid threat;
- Vaczi (2016): levels of intensity of threats and intentions of actors involved are studied to distinguish between hybrid threat, hybrid conflict, and hybrid war.

By examining the diagram proposed in the picture below, the threshold, as identified in the model of Cayirci Bruzzone et al. (2016), could lie somewhere between the accumulation of Hybrid Warfare into a Hybrid Conflict and the Hybrid Conflict intensification into a Hybrid War. However, in the Balaban & Mielniczek model the circumvention and the deliberate willing to ignore War and Humanitarian Laws is considered a sort of a "chemical" by-product of the Hybrid Warfare, rather than one of its pillars, or preconditions to be met; instead, the circumvention of International Law in the Hybrid Warfare Model by Cayirci, Bruzzone et al. (2016), was instrumental for the denial of responsibility, and so necessary to keep the conflict below the threshold.

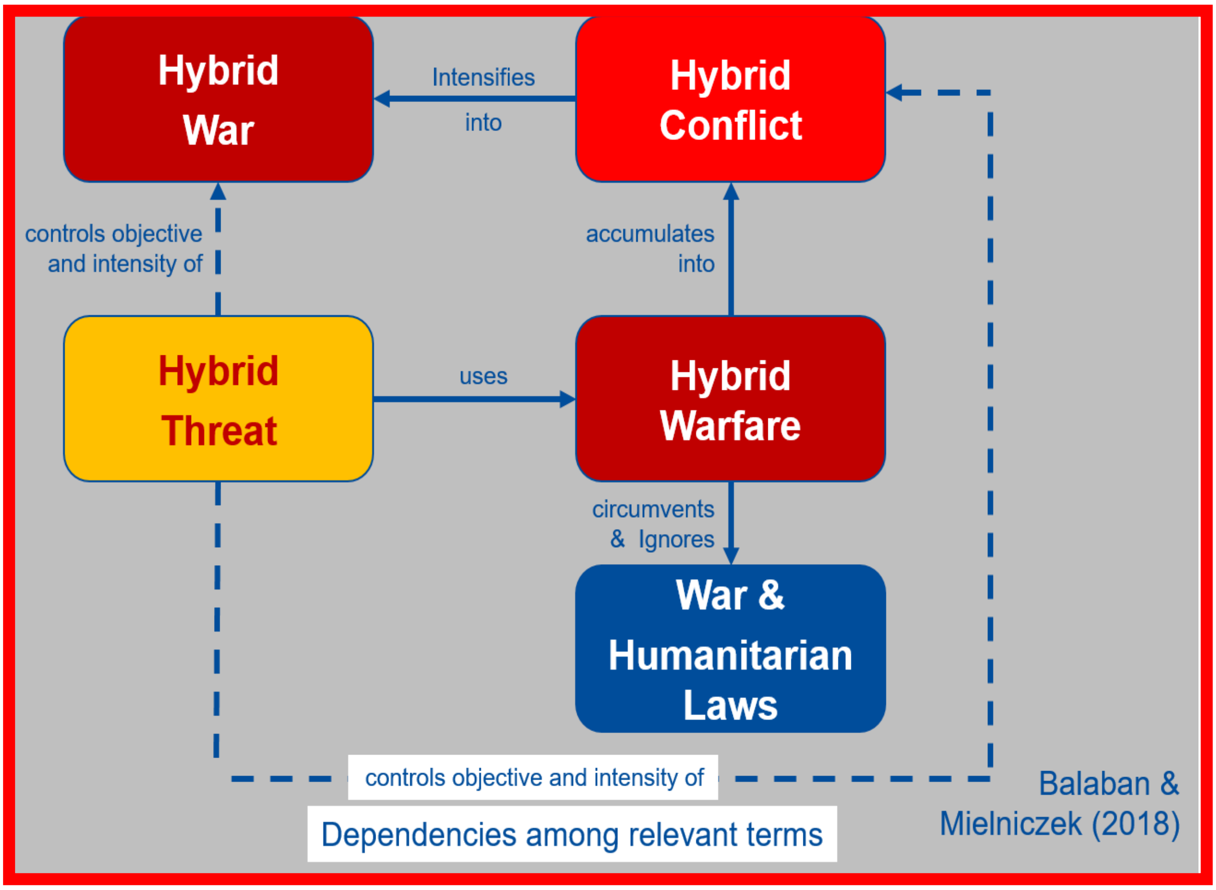


Figure 45 - Dependancy loop (Balaban & Mielniczek,2018)

The conceptual model proposed by Balaban & Mielniczek it is based on a theoretical Causal Loop Diagram of Hybrid Conflict, as depicted in Figure 45 and 46. In the loop, the intensity of hybrid attacks is controlled by attacker hostile objectives, and under those objectives increases with the expanded attacker hybrid warfare capabilities. The increase of intensity of hybrid attacks results in a higher damage to target, however increasing the intensity of countermeasures. The strictness of war laws (which however has not been imported into the diagram) defines the line between the Hybrid Conflict and Hybrid War, and it positively affects a perceived danger of conventional war. The perceived danger of conventional war increases with a growing intensity of hybrid attacks and with a growing intensity of countermeasures, but additionally generates feedback links decreasing both of its causal factors. The *damage to target* has a negative effect on its *relevant defence capabilities*, which has a positive relation with *intensity of countermeasures*. Both, *intensity of countermeasures* and *relevant defence capabilities* have positive relation with *damage to attacker*.

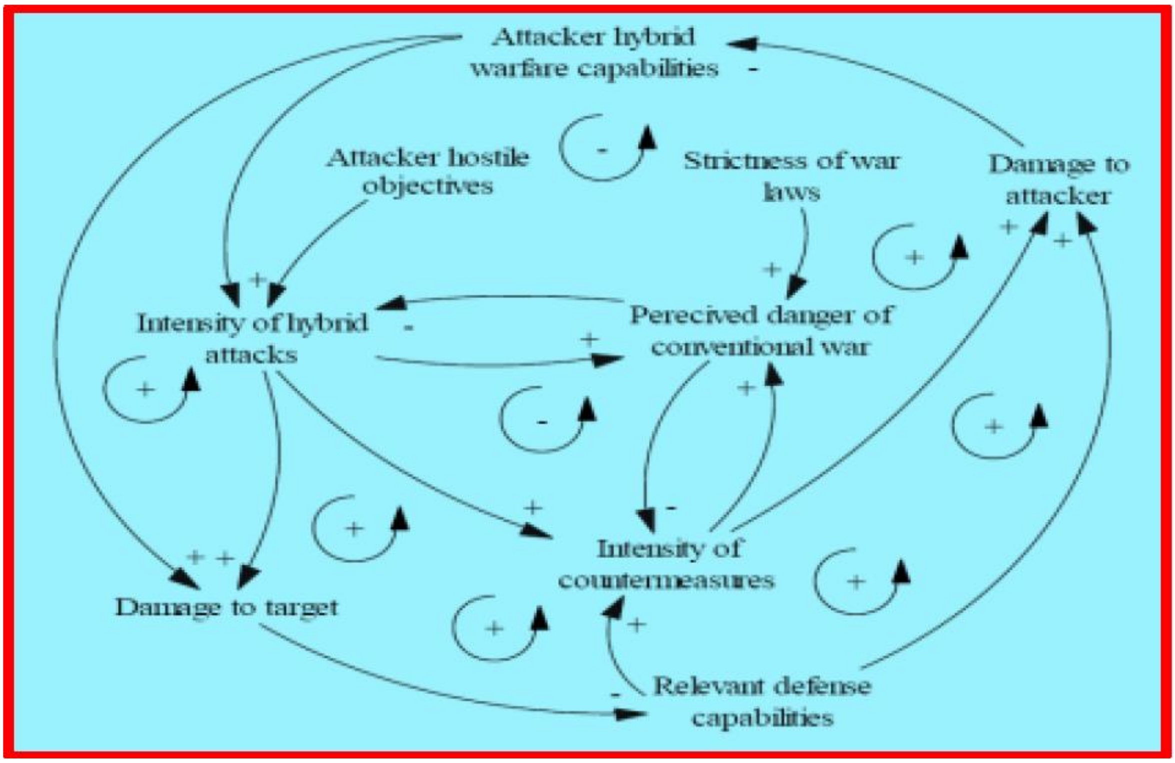


Fig 46 - Causal Loop Diagram (Balaban & Mielniczek, 2018)

Finally, the higher the *damage to attacker* the lower the *attacker hybrid warfare capabilities*, which has a positive relation with *damage to target*.

With only nine factors at a very-high level this conceptual model has eight dynamic loops: six reinforcing and two balancing, which indicates a high dynamic complexity of the system.

Figure 47 below shows implemented model of HC using Dynamic Bayesian Network (DBN). The model allows for temporal reasoning by including a number of time-slices that represent HC phases.

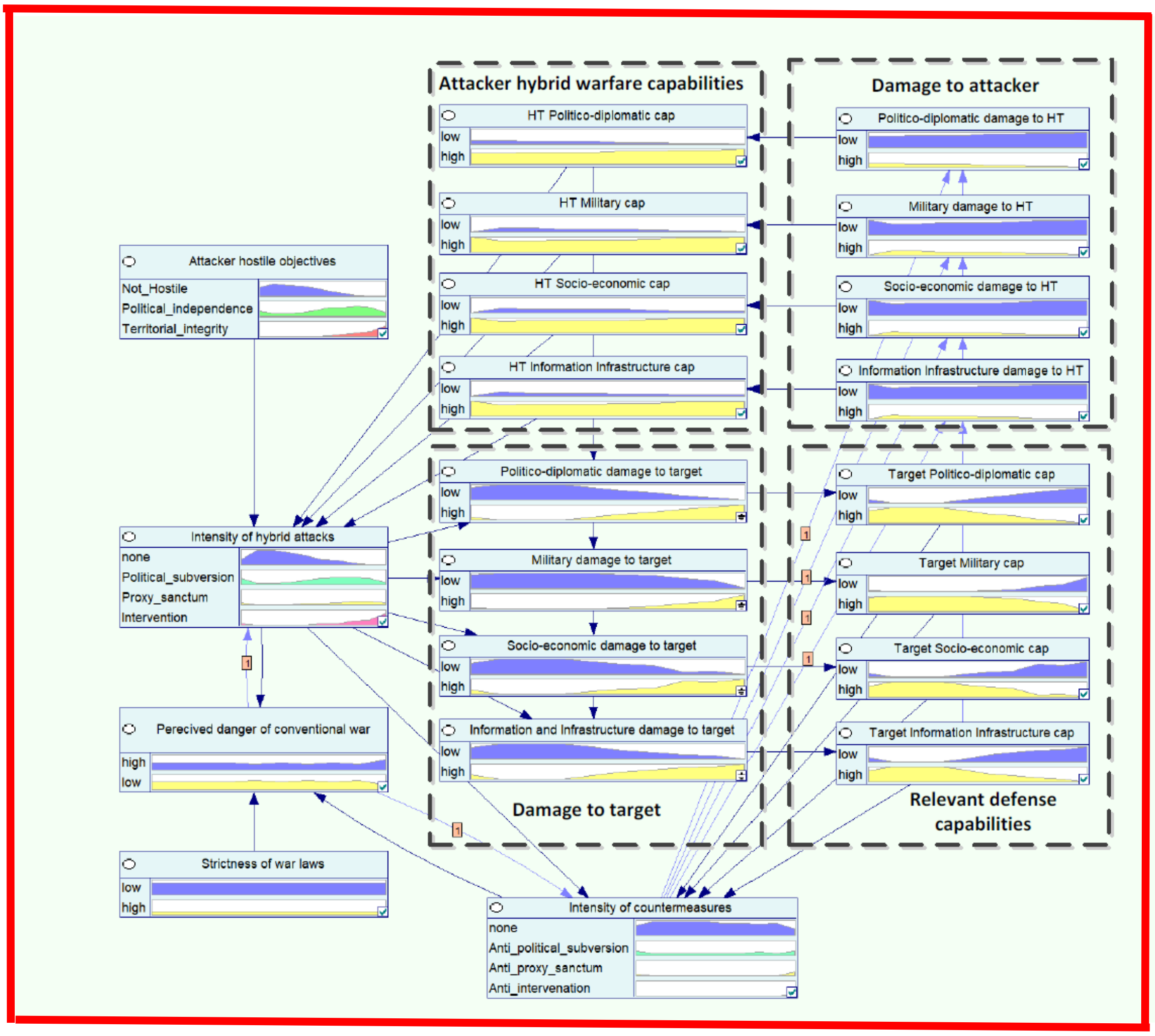


Fig. 47 - HC model implementation using DBN (Balaban & Mielniczek, 2018)

On that regard, Karber (2015), proposed four levels of HW intensity:

I) political subversion;

II) proxy sanctum;

III) intervention;

IV) coercive deterrence.

The first three levels are used in the node *intensity of hybrid attacks*. Levels one and two align with the HC definition, while the third level with the hybrid war. The open use of force threatening political independence or territorial integrity of a state is prohibited by Art. 2(4) of the UN Charter (UN 1945), which can explain the deceptive behaviour on the part of HT trying to circumvent UN. *Attacker hostile objectives* node considers these two objectives of HT. Threat against territorial integrity places a strong influence on intervention phase in the *intensity of hybrid attacks* node as compared to threating against political independence, which resorts to influencing political subversion and proxy sanctum phases. *Attacker hybrid warfare capabilities* are based on definition of HW. These four categories modulate *intensity of hybrid attacks*. Subsequently, *attacker hybrid warfare capabilities* along with *intensity of hybrid attacks* determine severity of *damage to target*, which are mapped along the same four PMESII categories, this time representing *damage to target*. *Damage to target* lowers *relevant defence capabilities* of the target. Conditional probability tables (CPT)s that define *intensity of countermeasures* should be based on a defence strategy against HT. For instance, if attacker uses political subversion then its target may want to counter this subversion and, probably even more importantly, take actions to prevent escalation of *intensity of hybrid attacks* into proxy sanctum level by employing appropriate, anti-proxy sanctum, *relevant defence capabilities* that will in turn *lower attacker hybrid warfare capabilities*. If attacker or defender considers to escalate beyond HC defined by Art. 2(4) of the UN Charter (UN 1945), they should *perceive danger of conventional war*. Given a sufficient evidence of 'bending' or violating UN laws both, attacker and defender risk, at least in principle, punishments by international community. Unfortunately, current war laws are not very strict and precise, inducing minimal negative feedback effects on *intensity of hybrid attacks* and *intensity of countermeasures*. The non-intervention principle enshrined in Art. 2(7) of the UN Charter leaves a large window of using HW as lawful, which encourages development of even more sophisticated HW. This, in a long-run, is a risky proposition. From a legal perspective, the authors argue that non-conventional methods of warfare are lawful as long as they are not prohibited or do not infringe principles of international humanitarian law, and because the window of interpretation may be large, the legality of warfare used may need to be analysed. However, such analysis could be unsuccessful for many reasons, first of all, because before being legal it is political driven, and second because the International Community very unlikely will agree on a common understanding of what is legal and what is not on this particular, very divisive subject which is Hybrid Warfare. From this point of view, indeed many in the West look at Hybrid as a concept vague, un-helpful and even misleading (Van Puyvelde, 2015; Radin, 2017), even not suitable as an analytical tool for assessing, in particular, Russian military capabilities or foreign policy intentions (Renz & Smith 2016). Indeed, Russia's successful use of non-military instruments, in the annexation of Crimea was the reason why the 'hybrid warfare' label has gained so much traction in its aftermath, even though the military component, with the seizure of airports, barracks etc., was instrumental for the success of the operation.

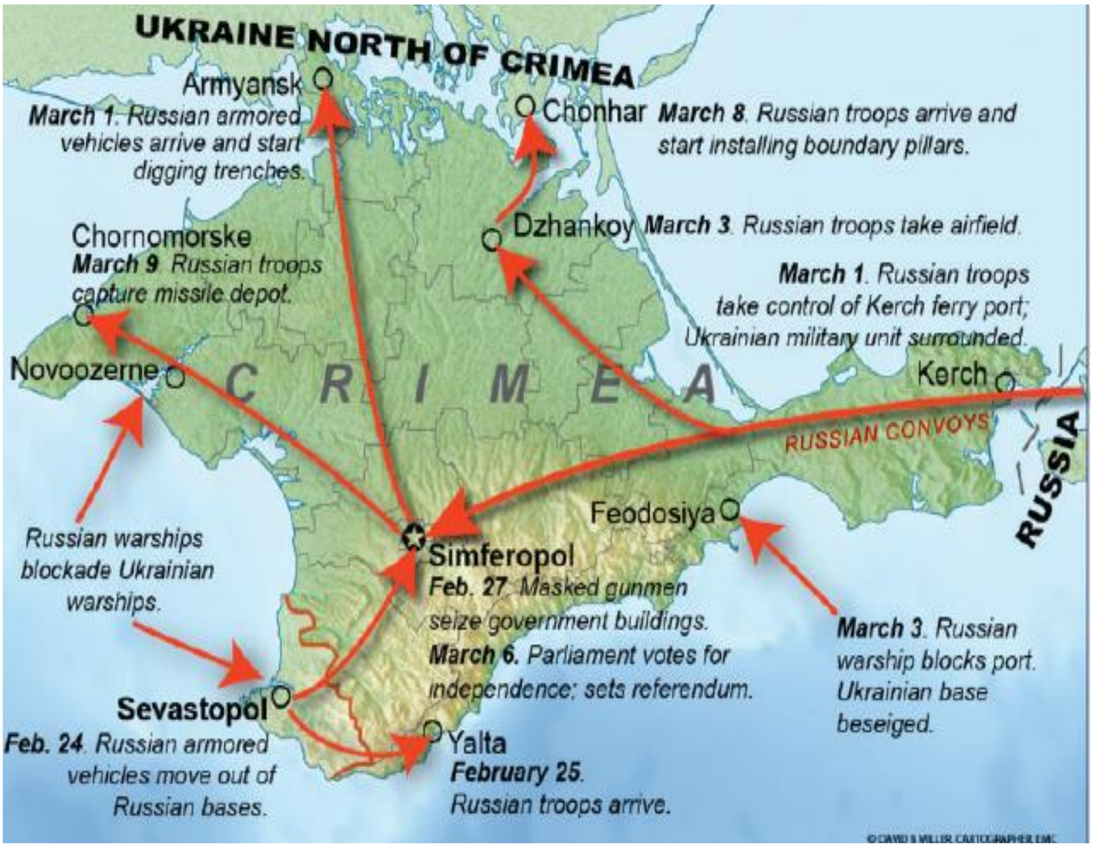


Fig. 48- Timeline of seizure of Crimea, by Miller B.M., in Kennan cable n.7/2015

Seizure of Crimea should be considered as a singularity, but still in the paradigm of Hybrid Warfare. This because it began as a covert military operation, combining ambiguity, disinformation, with more traditional aids such operational surprise and electronic warfare, followed by a traditional military invasion of the peninsula, carried out by Russia's airborne, naval infantry, and motor rifle brigades. This operation was unique, because Russia's Sevastopol naval base, status of forces arrangements (SOFA) in Crimea, and additional agreements on transit of troops in Ukraine enabled deployments and tactics that would not otherwise have been possible. However, the success achieved by this operation is not easily reproducible elsewhere; so, more than an example, it represents a paradigm, the pinnacle of Hybrid Warfare (Kofman & Rojansky, 2015).

For the reasons above then, according to the author, Hybrid Warfare paradigm is a tool to examine any conflict/attrition, not limited to be applied (and least of all, to be applied because of ideological reasons) to this or that country in particular, but overall it is an instrument to gain awareness of the reality. In such contest, political, civil and military leaders and their staff are in the need to exercise themselves with M&S tools in order to test and refine various ideas and procedures on how to deter and counter Hybrid Threats from whatever direction they arrive. This because one must think like in terms of HT to understand its objectives, potential phases of conflict, actions, and decisions (Davis Jr., 2015). In the current situation, more work on simulation models of HC is needed in order to allow the development of higher predictive and prescriptive models, that will enable preventive, early warning and retaliatory countermeasures against Hybrid Threats. At the moment, the time required to develop such complex capacity is prohibitive and so new technological approaches are required to face this challenge. The M&S environment should be able to represent complex Hybrid Conflict at multiple levels: political, strategic, operational and tactical - not limited to common principles of warfare and common hierarchy of combat models. A combination of multi-method (Balaban 2015b) and multi-resolution (Petty et al. 2012; Rabelo et al. 2015; Zeigler, 2017) M&S is likely needed to achieve this vision.

1.7.3 Considerations

The Hybrid Conflict Modelling proposed by Balaban & Mileniczek (2018) has the merit to be very comprehensive at describing through Causal Loop Diagram the accumulation of Hybrid Threats and the consequent transformation into Hybrid Warfare and then War. It describes very well a theoretical model of a Hybrid Conflict employing a Dynamic Bayesian Network to demonstrate its application. More arguable is the speculation about what is legal and legitimate in a Hybrid Conflicts and what is not, this because the inherent political and highly divisive meaning of the concept. In any case, because one of the main objectives (for the aggressor) in Hybrid Warfare is avoid the direct military conflict, the model of the threshold, as proposed by Caiyrci, Bruzzone et al. (2016), remains critical to comprehend Hybrid Warfare and its unforeseen escalation into a full armed conflict. Moreover, inside the model proposed by Balaban & Mielzniczek, the "strictness of law" - which marks the boundary between Hybrid Conflict and Hybrid War - appears quite static if matched with the dynamicity and flexibility of the above mentioned threshold model, that for such reason is able to capture the evanescent, blurring line between Hybrid Warfare and the so called "Conventional Warfare".

In both cases, the modelling of Hybrid Warfare within DIMEFIL/PMESII_PT domains proposed by Cayirci Bruzzone et al. (2016) and by Balaban & Mileniczek (2018) are a courageous tentative to import, into the domain of particularly poorly understood phenomena like social, politics (and to a lesser degree economics - Hartley, 2015), the mathematical and statistical instruments and the methodologies employed by the pure, hard sciences. However, just using the instruments and the methodology of the hard sciences it is not enough to obtain the objectivity, and is such aspect the representations of Hybrid Warfare mechanics meet their limit: this is posed by the fact that they use, as input for the equations that represent the Hybrid Warfare, not physical data observed during a scientific experiment, but rather observation of the reality that assumes implicitly or explicitly a value judgment. Especially memory and frequency of past aggression, ethnic and religious division, narrative of the events – to name the most difficult to handle – imply a value judgement which has to be translated into a real number in order to act as input of our equations. Such value judgement it is subjective, and not objective like the mathematical and physical sciences, and if not managed well by the academic researcher it can introduce a bias; such bias, other than introduce an unacceptable distortion of the reality and so making useless the research for the purpose of the Science, it could be used to enforce a narrative mainstream, that contains a “truth” which lies outside the border of the Science. However, the author believes that going through a rigorous Verification and Validation process (V&V), M&S scientist can discover the impact of value judgement inside the model under development. Under this perspective, the importance of VV&A process is explained in paragraph 7 of the third chapter.

2. M&S tools and techniques for Hybrid Warfare

In the first paragraph we will examine simulation models for Hybrid Warfare through the employment of TREX simulator, while in the second paragraph – with the support of the DIES IRAE simulation architecture - we will describe the phenomena of mass migration, and how it could be added to the arsenal of the Hybrid Threats. In the third paragraph, we will examine a Joint approach to model Hybrid Warfare to support multiple Operations. In the fourth paragraph, with the support of CAPRICORN simulator, we will address the problems related to long vs short time strategic achievements. Moreover, it will be discussed the time factor in the contest of the Hybrid Threats and its effects on the development of National Defence and Foreign Policy, and how the nascent discipline of Strategic Engineering can support strategic planning for homeland security.

2.1. Simulation Models for Hybrid Warfare: T-REX

The security environment, or at least his perception, has been continuously changing and deepening in complexity during the last twenty years (Vos Fellman et al. 2015). The evolution of Internet and media channels as well as globalization emphasize the impact of specific concurrent actions carried over different channels (e.g. political, social, financial, cyber, etc.); for these reasons, the (NATO) Alliance is studying intensely these new phenomena often aggregated under the name of Hybrid Warfare (Baker, 2015). Indeed, one of the main characteristics of this kind of warfare is that it includes several types of means, activities and actors combined each other; civil as well as paramilitary, military and irregular actors, try to achieve political and strategic objectives trough overt and covert actions and conventional and unconventional means. This contest has been addressed very well by Russian Army Chief of Staff, General V. Gerasimov, when he affirmed that “countries bring a blend of political, economic and military power to bear against adversaries” (Gerasimov, 2013).

Hybrid Warfare focuses often to complicate the decision-making process, being especially effective against organization that are slow in their decision process, because of their inherent structure or due to their pluralistic or multinational nature. In this context, the subjects of war activities are often intentionally ambiguous in order to avoid a direct military confrontation. It is evident that the modern concept of Hybrid Warfare is pretty complex and requires specific models and studies; due to these reasons the NATO Foreign Minister in the December 2015 meeting approved a specific strategy addressing hybrid warfare, which involves the full Diplomatic/Political, Information, Military, Economic, Financial, Intelligence, Legal (DIMEFIL) spectrum. In this case the war is conducted in all battlegrounds (Liang & Xiangsui, 1999), involving conflict zone population as well as home front population, so the models of engagements are the most different; considering the nature of the Hybrid Warfare, it is necessary to conduct an analysis over a spectrum of alternative multiple layers (McCuen, 2008; Weitz, 2009; Gerasimov, 2013; Bachmann & Gunneriusson, 2015; Davis Jr., 2015).

The actors of hybrid conflicts belong to different types including both state and non-states; from this perspective hybrid warfare is a concrete and actual phenomena in many conflict zones, and it is supposed that any belligerent is using hybrid means and strategies. On that regard, it is worth remembering that one of the pillars of hybrid warfare is to avoid direct military conflict - as much as it is not necessary – preferring overt military actions just as coadjutant to the whole plan. In order to investigate this context and study possible scenarios, it is evident the potential of Modelling and Simulation (Christman, Di Giovanni and Wells, 2015; Schmidt 2015; Balaban& Mielcnizek, 2018). Simulation is an important methodology to study such complex environment which includes different domain and layers as well as stochastic factors; for instance, the human behaviour as well as cyber, conventional and information warfare should be covered by specific models. All these aspects have been studied extensively in modelling and simulation, even if the complexity related to their mix within Hybrid Warfare is a new subject of research and investigation.

Several researches about complex scenarios had led to the creation and the use of Intelligence Agent (IA) for recreating model of human behaviour since many years (Shonkwiler et al. 1986; Avalle, Bruzzone et al. 1996,1999; Castelfranchi & Conte, 1996; Dascalu et al. 1998). The intensification of the use of the IA conducted to the development of several tools to support modelling development (Resnick 1996; Ferber et al. 1998; Parunak et al. 2006; Bruzzone et al 2014a, 2014b; Zhang 2016). More recently, the use of Multi Agents and Intelligent Agents allowed to reproduce complex situation including human behaviour (Takadama et al. 2007, Takadama et al. 2008; Bruzzone & Massei 2010; Macal & North, 2010; Joo et al. 2013; Cai et al. 2013). Simulation Team has been extremely active in the field of Human Behaviour Modelling: it has developed complex models about PSYOPS, CIMIC Operations, Civil Disorders, Decision Making, etc. The peculiarity of IA-CGF NFC (Intelligent Agent Computer Generated Simulator Non-Conventional Framework) developed by Simulation team is that the Agents are able to take advantage of specific events for their operational planning (Bruzzone 2013d; Massei & Tremori 2014; Bruzzone et al.2015b; Di Bella 2015).

In particular T-Rex (Threat network simulation for REactive eXperience) is an interoperable MS2G (Modeling, interoperable Simulation & Serious Game) solution developed by Simulation Team. T-REX is a stochastic discrete event simulation able to act in stand-alone way or federated with other HLA simulators. T-REX could be executed in real time or fast-time, and in this second case it allows to conduct multiple runs to investigate alternative solutions for vulnerability reduction respect Hybrid Warfare. The proposed simulator is currently demonstrated over a scenario related to a desert area bordering with sea and including five towns; the simulation includes multiple layers simulating population (e.g. individuals and/or families) as well as interest groups (e.g. industrial sectors, religious groups, social classes); these elements are structured within social networks and regulated by mutual relationships expressed by fuzzy variables in terms of attitude and intensity.

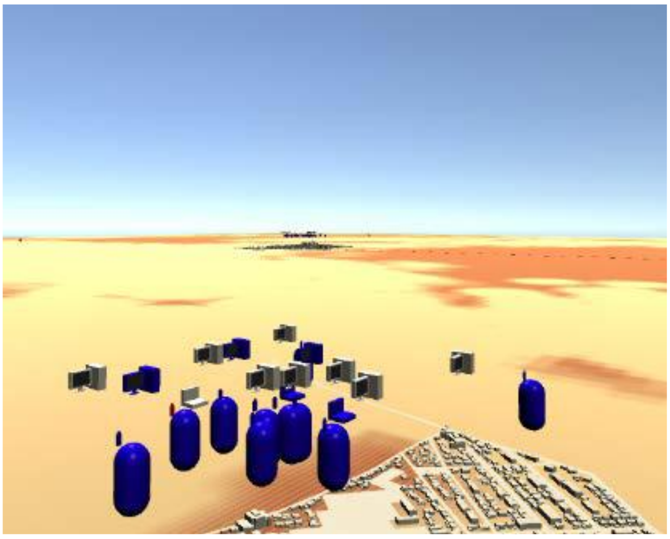


Fig.49 - T-Rex terrain caption

T-REX includes also other layers interoperating with the socials, in particular the Entity & Units reproducing military units and assets that influence population behaviors. The proposed scenario includes the power grid, cyberspace and communication network. Indeed, the Cyberspace is reproduced modeling the IP address of all fixed and mobile ICT (Information and Communications Technology) elements as well as their related interconnections; each node and link could be attacked by compromising its availability, integrity and/or confidentiality and it is possible to conduct defensive, offensive and restoring actions. In T-Rex all elements evolved dynamically and are driven by the IA-CGF reproducing a Hybrid Warfare situation; in addition, the simulator could be federated within an HLA Federation with other models. Currently the scenario includes also traditional and virtual assets on the area as well as a Power Plant, a Desalination Plant, and a tank farm that are critical infrastructures in the area.

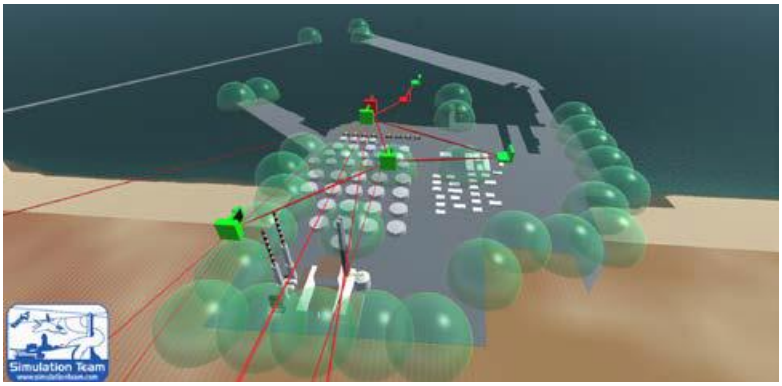


Fig.50 - T-Rex: caption of port security issues

In conclusion, it emerges that the most innovative researches within modelling and simulation community could be strategic for addressing almost all the areas of different layers of Hybrid Warfare. So actually, there are favorable conditions to implement and develop models of Hybrid Warfare, such as the T-Rex, in order to develop tools and war-games for studying new tactics, collective training and to support decisions making and analysis planning.

2.2. Hybrid Warfare: *Weaponization* of Mass Migration

We have seen in the model of Hybrid Warfare proposed by Cayirci, Bruzzone et al. (2016) how the parameter *"d"* – dealing with ethnical and religious divisions – and *"h"* – dealing with how much such divisions bring tolerance or discrimination - may help the owner of the Hybrid Strategy. It is evident that a massive, quick dispatch of migrants across one's border country can alter dramatically the above two parameters in favour of a potential aggressor; further elaborating on those parameters, it is then necessary then to look how mass migration can (an unfortunately, will be) "weaponized" in order to ignite a crisis.

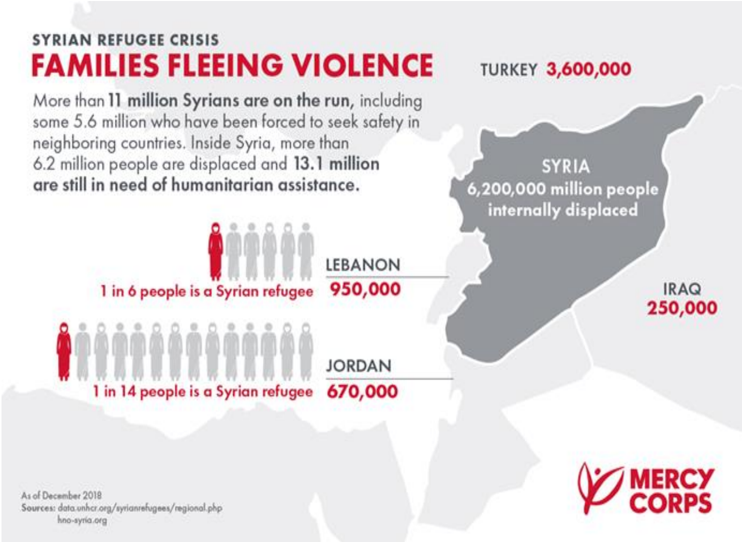


Fig. 51 - Fleeing Syria, 2011-2018 https://www.mercycorps.org/countries/syria

Let's now reconnect with the description of Hybrid Warfare made at paragraph 1.1 in order to recall that any element of the Hybrid Threat is not necessarily be illegal or pose a threat in their own right, but their combination could threaten individual Governments or a whole Alliance; having clarified that, we are going now to examine a current situation.

In the second week of October 2019, the attrition between Republic of Turkey and ethnic Kurds located within the confines of Syria escalated due to a cross-border military operation conducted by Turkish regular armed forces (allegedly supported by irregular/militia hostile to Kurds), resulting in a tense situation, foreshadowing unpredictable and dangerous outcomes. The response of both USA and European Union has been to condemn the aggression, and in return current Turkey's president threatened to flood Europe with refugees as the humanitarian crises become more and more acute (https://edition.cnn.com/2019/10/10/politics/syria-turkey-offensive-displaced-intl-hnk/index.html); however, this means practically "weaponizing" mass migration, and so applying a "Hybrid" pressure on his own allies (in NATO). Turkish President knows very well how the phenomena of mass migration struck at the gate of Europe. An (unexpected?) ally for him could be the block of the so called either "populist" or "sovereigntist" parties (on the rise across Europe), which have easy arguments in accusing European Union and established parties of selling out the nation's cultural core to migrants (Lochocki, 2018).

The phenomena of "weaponization" of mass migration has been extensively analysed in the eponymous book of Kelly M. Greenhill (2016), in which it is argued that foreign policy decisions in some cases resulted in the exercise of a particular kind of covert coercion, which is the intentional creation, manipulation, and exploitation of real or threatened mass population movements; such means are widely deployed but mostly unrecognized as an instrument of state influence. Examples of how often this type of coercion has been attempted, how successful it has been, who employed this tool, to what ends, and how and why it works etc., are presented. The conclusion drawn are that the owner(s) of a coercion strategy based on exploitation of mass migration want to affect target states' behaviour by exploiting the existence of competing political interests and groups, and so manipulating the costs or risks imposed on target state populations. This strategy deploys two effects: the first relies on alarming the public opinion with threats of a massive refugee flux, overwhelming a target's capacity to accommodate those; the second, a political blackmail by cynically exploiting the existence of legal and normative commitments to those fleeing violence, persecution, or privation.

Useless to say, international migration flows towards developed countries are continuously growing creating complex scenarios from several points of view including security, social, political and economic aspects (Ratha et al. 2016). In particular, the global labour market, immigration policies and geopolitical situations are crucial drivers that affect these aspects since several years (Johnston 1991; Fehr et al. 2004; Castles 2004; Samers 2004; Smith 2013). It is interesting to consider the specific situation of Europe that is currently affected by impressive flows from Africa and that is trying to identify actions to regulate this phenomena and related demographics (Van Houtum & Pijpers, 2007). Traditionally these phenomena are analysed by geopolitical point of view or just by statistics (Samers 2004). Therefore, the presence of so many factors dynamically interacting and affected by human behaviour and stochastic factors suggest today to develop quantitative models able to address these scenarios as it has been done already in similar cases (Bruzzone et al. 2014a).

In the present paragraph it is proposed a modelling approach to represent the complex reality of mass migrations, which stands in a blurring area where the borders among Defence, National and International Security vanish; as such, and for the reasons exposed above, (unfortunately) it could be employed as a hybrid tool (Bruzzone et al., 2017e). The demographics and generic statistics are used as input data, while human behaviour models are used to represent the phenomena as well as the interactions among the different key factors; the development of the conceptual model addresses the migration flows between Africa and Europe with a focus on a specific case inspired by the proposal of an agreement between EU and Nigeria, the so called "Migration Compact" (2016). Due to these reasons, it is proposed the use of advanced Human Behaviour Models based on dynamic stochastic simulation to address a specific context, which is the European African Agreement in matter of migration and consequence on the social situation (Mountford & Rapoport, 2016). In particular, the proposed case addresses a specific African area, inspired to Nigeria case (Parfitt 2016). Useless to say, the consequences of wrong decisions in terms of policy are very dangerous, affecting the whole population in terms of economy, security, stability, equality, sustainability in host Countries as well as in origin Countries. Due to these reasons the presented work has been titled "Male Nostrum": a word pun from Latin around the name "Mare Nostrum", that is the original name of the operation to protect Mediterranean Sea Border and to guarantee safety of life at sea for African immigrants sailing to South Europe on poor boats (Bjarnesen 2015). However, "Male Nostrum" is to vocative case related to *Our Bad Problems* and is a pretty synthetic expression dealing with the critical aspects related to properly act respect migration flows: a framework so interdependent, complex and big to require simulation even just to understand the whole boundaries of the problem and the potential of the different Courses of Actions.

The proposed model combines previous cases based on Intelligent Agents - Computer Generated Forces (Bruzzone et al. 2011b; 2014a; 2017e), and represents a preliminary research on modelling complex immigration scenarios considering human factors and stochastic elements related to multiple layers.

2.2.1. Models of World Demographic

Along the last decades the immigration flows in Europe were subjected to a continuous increase due to many reasons, among them the economic ones are usually dominant (Borjas & Crisp 2005); indeed, these flows are mostly moving towards the richest parts of the European Continents from some major directives as summarized in table 2 (DESA 2013; 2017). These phenomena are results of the world wide demographics and several social and political aspects (Ratha et al.2016; Joly 2016). Also the simple pressure related to the world population growth is by itself a very important factor considering that is expected to increase from the current 7.4 billion to 10 in 2053, as proposed in figure 52 (DESA 2013; Infoplease 2016, PRB 2016). In this context of demographic pressure, the economic inequalities should be considered in order to identify motivation to move and migrate (Scheve & Slaughter, 2001; Bourguignon & Morrison 2002). Indeed, it is possible to adopt a very simple model about these elements inspired to GDP (Gross Domestic Product), GNI (Gross National Income) and GNDI (Gross National Disposable Income) indicators (Ladenfeld, 2000; Yaşar, 2015; Yoshihara & Veneziani, 2016).

Table 2 – Overview of migration flows to Europe

Continent of Origin of the Immigrants to EU	*Immigrants to Europe [millions of people]*	*Percentage respect EU Population [%]*	*Percentage of Total EU Immigrants [%]*
Europe	37.8	7.48%	52.28%
Asia	18.6	3.68%	25.73%
Africa	8.9	1.76%	12.31%
Latin America	4.5	0.89%	6.22%
Oceania	1.6	0.32%	2.21%
Northern America	0.9	0.18%	1.24%
Total	**72.3**	**14.31%**	**100.00%**

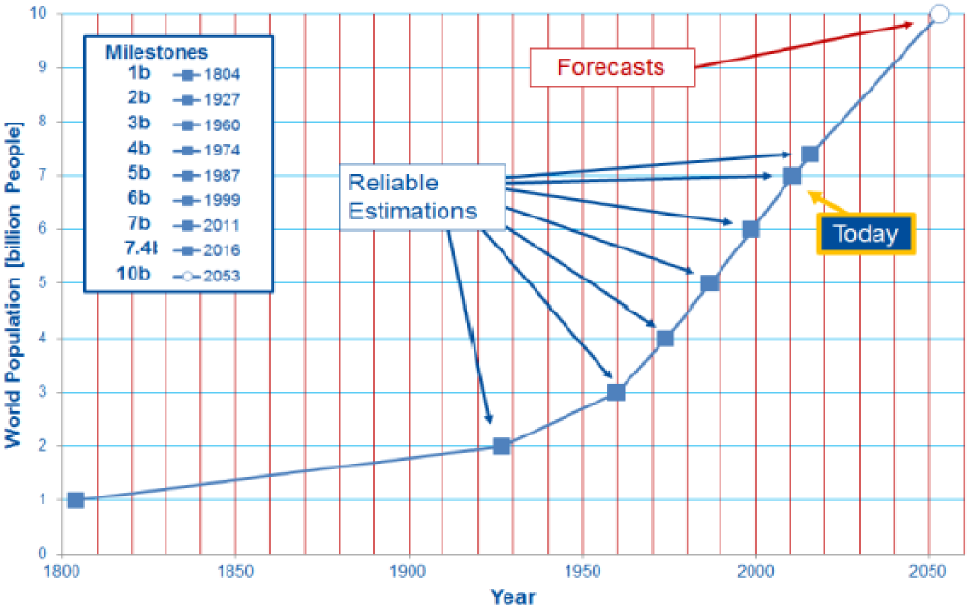


Fig. 52 – World Population Evolution

Region	*Regional Population [millions]*	*People under GAI [%]*	*People under GAI [millions]*	*Region vs. World Population [%]*
Large Europe	831	10.6%	89	15.3%
North America	360	0.0%	0	6.6%
Latin America	600	26.1%	157	11.0%
Oceania	29	0.0%	0	0.5%
Middle East	127	46.3%	59	2.3%
Central Asia	1,840	85.9%	1,581	33.8%
Far East	2,393	86.9%	2,079	43.9%
Africa	1,214	99.6%	1,209	22.3%

Table 3 – Regions and People under average income

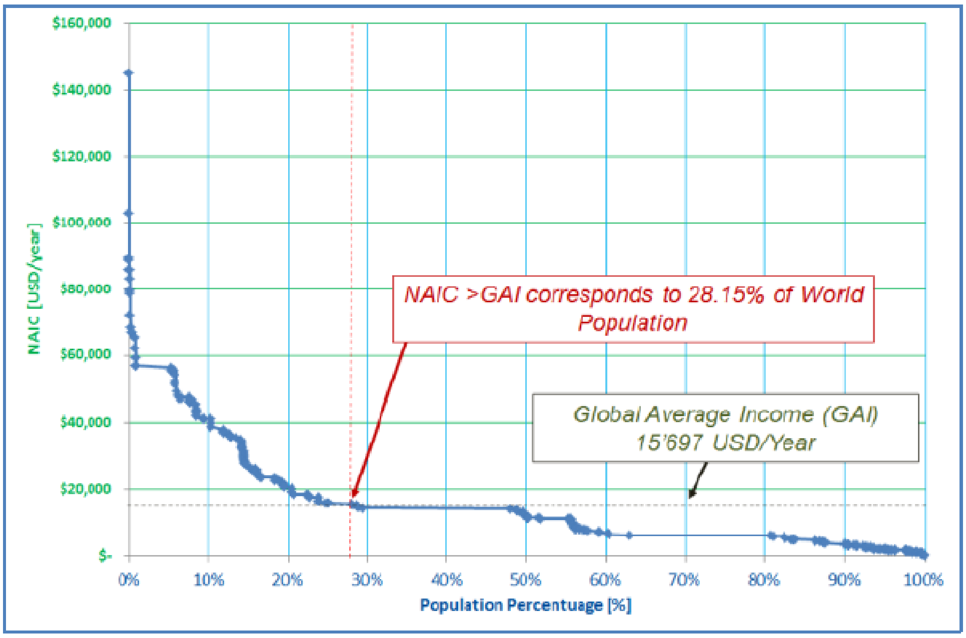


Fig. 53 – Richness and Population in the World

It is possible then to define an average level of per capita income for a Nation expressed as:

$$NAIC = kx\frac{C + I + G + TB + NFS + NUT}{PP}$$
$$NUT = UF_{In} + UT_{Out}$$
$$NFS = EX_{FS} + IM_{FS}$$
$$kx = k_{cul} \cdot k_{nat} \cdot k_{pp}$$

NAIC	National Average Income per Capita
PP	Population
C	Personal Consumption Expenditures
I	Gross Private Domestic Investments
G	Government Spending
TB	Trade Balance
NFS	Net Factor Income from Abroad
NUT	Net Unilateral Transfer
IM_{FS}	Value of Imports of Factor Services
EX_{FS}	Value of Export of Factor Services
UF_{Out}	Value of Income Transfer Given
UF_{In}	Value of Income Transfer Received
kx	National Corrective Factor
k_{cul}	corrective factor based on National cultural background of the population
k_{pp}	corrective factor based on National Purchasing Power
k_{nat}	corrective factor based on National Characteristics

Equation 9 – calculation of NAIC

It is evident that this approach is very simplified and miss to consider important aspects such as internal inequalities, relative purchasing power, etc. (Arghiri 1972; Fox 2012; Kakwani & Son, 2016).

It is interesting that while NAIC should be used to consider the differential between nations to estimate desire to migrate of the population, the advances in communication and transportations are making evident that emigrants move towards most attractive countries on a global scale considering global differential. Due to these reasons it is introduced a factor corresponding to Global Average Income (GAI) that is expressed as:

$$GAI = \frac{\sum_{i=1}^{NW} kx_i(C_i + I_i + G_i + TB_i + NFS_i + NUT_i)}{WPP}$$

NW Total Number of Countries of the World
X_i Indicator for the i-th Country
WPP Overall World Population

Equation 10 – GAI calculation

The GAI could be used as a rough estimation of country population desiring to migrate comparing their NAIC with GAI as threshold level; obviously this provide just an order of magnitude to estimate the quantity of people motivated to move. From this point of view, it is important to consider that just 2.08 billion people (28%) live in countries that are over NAIC (around 15’690 USD/year) of the whole planet based on some available data as proposed in figure 2 (DESA 2013; Infoplease 2016, PRB Report 2016, CIA World Fact Book 2016). Considering the improvements in communications and mobility this obviously generate a huge flow that is expect to growth in future despite specific spot events (e.g. wars, revolutions, famine) occurring periodically (Ratha et al.2016; UNHCR 2015b; Kegley & Blanton, 2015). Indeed, these statistics are mostly reconfirmed even by more recent analysis (DESA 2017) and highlight a huge flow overpassing 70 million people arriving mostly from Easter parts of Europe as well as from Asia and Africa.
The aging of the population in rich countries, (a fact that is even present in poor world due to improvements by health support despite the medium long period effect), are another important drive to compensate the labour force need of consolidated economies (Johnston 1991; Magnus 2012; Paradiso 2016).
It is evident that these phenomena need to consider human factors, religion, ethnics, cultural background in order to evaluate consequence of these decisions and not just statistics (Levine et al. 1985; Levitt 2007; Bruzzone & Sokolowski, 2012). From this point of view simulation could contribute providing a framework to develop valuable models including HBM (Human Behavioural models) providing

quantitative results that could support evaluation of risks and effects of alternative decisions (Bruzzone & Massei 2010).

2.2.2 The proposed model architecture: *Dies Irae*

Human Behaviour Models could rely on different data provided by Subject Matter Experts (SME), Sociometric Data, etc (Moreno 1951; Jennings 1987; Capone & Mey 2016); recently use of Internet of Thinghs (IoT) and Social Networks are enabling new opportunity to model Human Behaviours (Eagle & Pentland 2006; Lane et al.2010; Kalter 2016). In facts the use of intelligent agents for creating HBM resulted very flexible and effective (Bonabeau 2002; Bruzzone et al.2011b).
Based on these considerations it was decided to adopt a multi-layer approach able to combine different Modelling and Simulation (M&S) techniques including stochastic discrete event simulation and agent driven simulation. In particular, it is proposed the tailoring of the IA-CGF through the creation of a NCF (Non-Conventional Framework) simulation derived from *DIES IRAE* (Disasters, Incidents and Emergencies Simulation Interoperable Relief Advanced Evaluator) used in previous scenarios (Bruzzone et al.2016a). Indeed, the architecture is similar to that one developed for SIMCJOH project (Simulation of Multi Coalition Joint Operations Involving Human Modelling) adapted as proposed in Figure 3 (Bruzzone et al. 2015b). In facts the *DIES IRAE* is based on MS2G (Modelling, Interoperable Simulation and Serious Game) Paradigm (Raybourn 2012; Bruzzone et al.2014d) and it is composed by different simulators that are open to be federated in HLA (High Level Architecture):

- **DIES IRAE VIS** (Virtual Interoperable Simulator): as stochastic discrete event agent driven simulation based on IA-CGF; this model includes HBM and simulates the actions of components, equipment, units and population.
- **DIES IRAE VIC** (Virtual Interoperable Commander) is a Virtual Simulator adopting Serious Game approach that generate the Synthetic Environment where the events are occurring in order to be able to support individual and collective training and education.

- **DIES IRAE SOCKS (**Social Kinematics Simulator) is a discrete event model able to take care of demographics and social dynamics to incorporate the high level models of social dynamics**.**

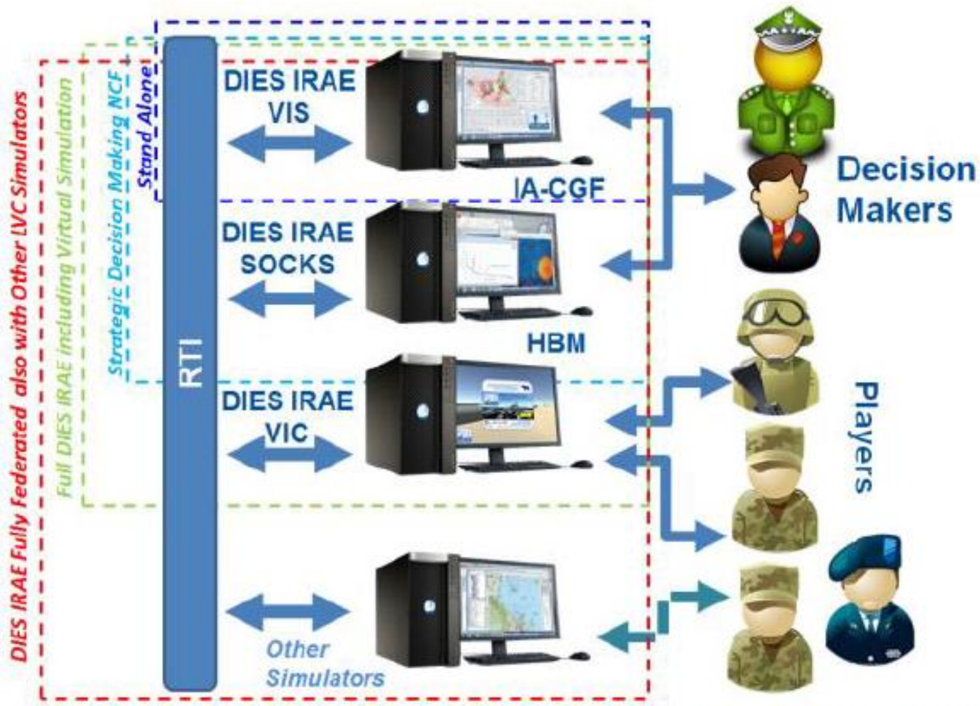


Fig. 54 – DIES IRAE VIS/VIC/SOCKS Architecture

This extension of DIES IRAE is further expendable by the use of HLA (High level Architecture) interoperable standard that allows to federate this structure with other models and simulators; for instance, it could be possible to combine this simulation with other war-gaming solution to support Experimentation, Policy Definition, Operational Planning as well as training within CAX (Computer Assisted Exercise). Indeed, as proposed in Figure 3 the DIES IRAE could operate in multiple modes including among the others:

- ***Stand Alone***: Just DIES IRAE VIS simulating by IA-CGF the population dynamics of the migration in the scenario
- ***Strategic Decision making NCF***: combining DIES IRAE VIS and SOCKS to reproducing strategic dynamics as well as impact of COA (Course of Actions)

- ***Full DIES IRAE***: DIES IRAE complete NCF combining VIS-VIC-SOCKS to include also virtual representation
- ***DIES IRAE Fully Federated also with external LVC Simulators***: in this open case the HLA allows to federate the whole DIES IRAE NCF also with other Simulators (Live, Virtual, Constructive) compliant with HLA.

So by this approach it is possible to use the simulator from stand-alone structure to fully federate, so the architecture is flexible and supports from a single user to a wide distributed simulation.

Indeed, among the factors considered to be included in the DIES IRAE SOCKS, the following variables are considered:

 Independent Variables

o Birth Rates

o Family Structures

o Population at Origin Country

o Population at Host Country

o Distribution of Incomes per capita at Origin Country

o Distribution of Incomes per capita at Host Country

o Existing Migration Flows

o Percentage of Regularized Immigrants

o Political Situation in the Country of Origin

o Political Situation in the Host Country

o Criminality exploiting Human Trafficking

o Unemployment Rate at Country of Origin

o Unemployment Rate at Host Country

o Attitude of the Security Council Members

o Special Interest of major Players (Western Nations Europe / China and Russia)

 Directly Controlled Variables

o Immigration flows from Africa along the period 2026-2030 from sub-Saharan Areas

o Evolution of Migration Flows

o Evolution of Population at Origin Country

o Evolution of Population at Host Country

o Change in Distribution of Incomes per capita at Origin Country o Change in Distribution of Incomes per capita at Host Country

In addition to the Controlled Variable by applying DOE, it could be possible to estimate the following Key Performance Indexes (Montgomery 2008):

o Influence of Birth Rate on Migration Flows
o Influence of unemployment on Migration Flows
o Influence of per capita income on Migration Flows
o Influence of social policies of countries of origin and destination countries on Migration Flows
o Effect of the Migration Compact in EU Migration Flows
o Xenophobia Level in host countries
o Success Rate of Populist Parties
o Terrorism Level in Host Countries

In facts, the final goal for the decision makers is to investigate the impact of different factors on the scenario, for instance in terms of effectiveness of Migration Compact between Europe and African Countries; as alternative it could be interesting to investigate the potential of applying alternative solutions such as a "Marshall Plan for Africa", as it has been done by USA at the end of the Second World War with the ERP (European Recovery Program, popularly known as Marshall, behind the name of the *pro tempore* US Secretary of State, George Marshall), in order to prevent/contain an "immigration phenomenon from them and to control the policies and economies of the countries beneficiaries of the plan" (Muller, 2016).
It could be interesting to evaluate the position and influence of other major players in Africa scenario such as China in case of failure of Migration Compact.
It could be important also to evaluate in European countries, the GDP and income evolution, the evolution of debts and the need of cheap labour for supporting economic growth; in general, it could be possible to evaluate indicators able to define the decline/rise of EU both in political and economic terms.
Indeed, the model should support also estimation of impact of critical events such as famines, floods and epidemics, civil wars due to ethnic and religious fragmentation with the emergence of new states to secede from existing areas as happen in

Katanga (Abi Saab 1978). These stochastic elements could be defined based on probability distribution influenced by simulation variable (Bruzzone, 2013d).

2.2.3. Migration flows & data for a realistic case study: Nigeria.

As example of available data to create a case study for completing the Verification, Validation of the model, it is proposed hereafter a realistic case study of migration based on current situation. This case is dealing with current migrant flows to Europe, with a special focus on African Western Routes involving Nigeria (see figure 4).

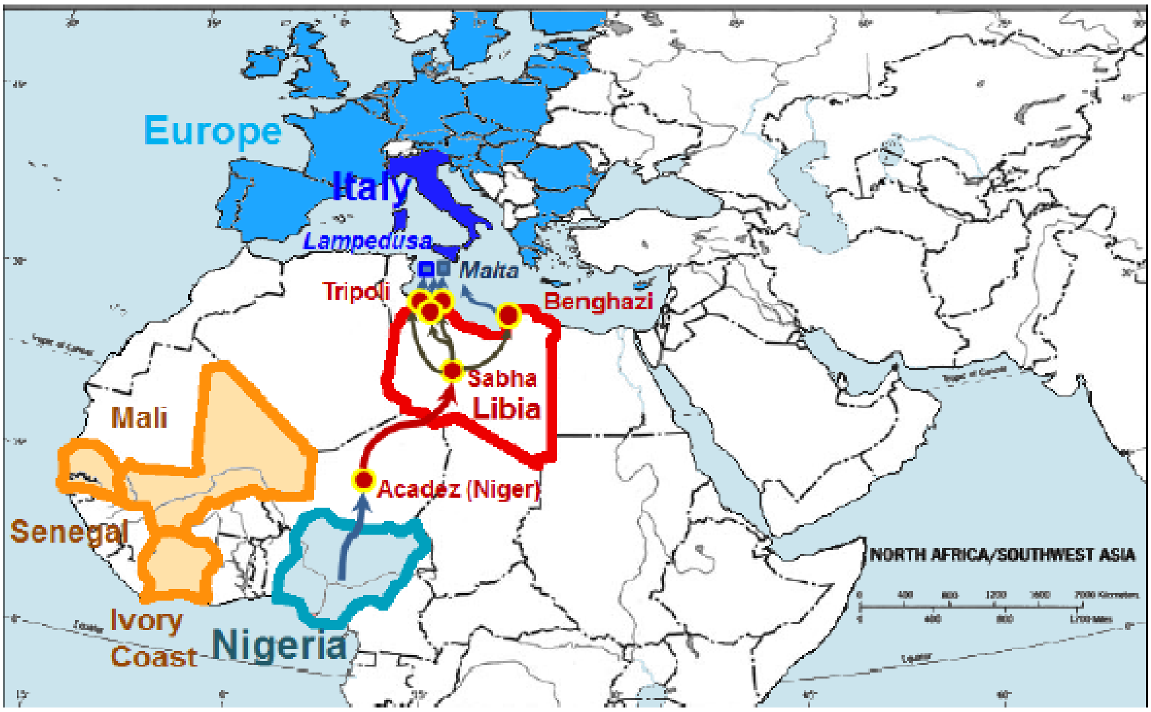


Fig. 55 – Migration routes from Nigeria to Europe

In facts Nigeria is the Africa's most populous country, with a rapidly growing population. In 2016 Italian Government proposed an agreement named "Migration Compact" between European Union (EU) and Africa's countries, with the scope of stabilizing the migration flow, trough legalization of the arrivals and a redistribution inside the EU of the migrants. The agreement however hasn't been implemented, but in its place was adopted the "New Partnership Framework (NPF), which has driven in the last four years the EU migration policy. Meanwhile, experiences and expectations about future migration flows have been extensively analysed both at international and national level, based on latest developments (Bjarnesen, 2015).

The data described below are the base that will be used to create the scenario for simulation; these data set are based on public domain sources available from Institutions and International Organization (UNHCR 2015, 2015b; ACLED 2016a, 2016b; IOM 2016a, 2016b, 2016c, 2016d; Sabbati 2015; UNICEF 2016).

Therefore, despite the specific value adopted it is evident that the proposed models could easily accept different values and hypotheses. Let's now examine the country.

Nigeria Facts:

- Nigeria population: Nigeria is the 9th most populous country in the world with an estimated population of 150 million of people, one out of five Africans is from Nigeria. The country has been undergoing explosive population growth and has one of the highest growth and fertility rates in the world; current estimations are corresponding to 182 million inhabitants in 2015 and 399 million forecasts for 2050 (DESA 2013).
- Nigeria Economic Situation: Nigeria is one of the fastest growing economies in the world. Petroleum and oil resources play a large role in the Nigerian economy. The country is the 6th largest producer of petroleum in the world; it is the 8th largest exporter and has the 10th largest proven reserves of it. Moreover, occurrences of uranium have been discovered in North-eastern states of Bauchi, Adamawa and Taraba, and as well as in Plateau, Kano and Cross River States. The government is planning to resuscitate its moribund cocoa factories at Idanre, suitable for chocolate with huge potentials for the production capacity.
- Social Situation: Nigeria possesses a huge inequality in terms of wealth and poverty among population (UNICEF 2016). Indeed, while the Country has vast oil wealth, the large majority of Nigerians is poor: 71% of the population living bad on incomes less than one dollar a day and 92% on less than two dollars a day. The local life expectancy remains petty low and is estimated to have further decreased from 47 years in 1990 to 44 years in 2005.
- Political Situation: Along the last years Nigeria experienced military dictatorship, corruption, political instability and poor governance; these reasons affected the Country development leading to very low investments in

infrastructures and basic services that are totally inadequate respect the population needs. In addition, the corruption is very diffused and represents one the principal challenges in Nigeria. However, while the Government has been conscious of this problem the efforts to combat corruption have been not really successful.

- Population and Collective Security: Along last months and years several thousand people have died in attacks led by insurgent and rebel organization, especially by Islamic State-aligned Boko Haram (BBC 2016). Indeed, the group has separatist aspirations that have further growth recently; they final goal is the establishment of a "State" where to impose Islamic law; the related successes in several northern areas of the Country have embedded divisions and caused thousands of Christians to move away. According to the "Armed Conflict Location and Event Data Project", between 1997 and the end of 2015 in Nigeria there have been 50,157 violent deaths (https://acleddata.com/tag/nigeria/)
- Nigeria Migration and Human Traffic: Indeed, there are many reasons to migrate from Nigeria. From this point of view, the major host of people moving out from Nigeria is Italy, where many of the migrants arrive from South Sea Border; this corresponds to the fact that Italy has the record of Nigerian asylum applications. Based on recent available data over 12 months (December 2014 - November 2015), the Nigerians who have applied for asylum in Europe are 31,460, of which more than half in Italy (17,895 equal to 57%). An important aspect of the increase in human trafficking form Nigeria has been the growing involvement of crime that is responding to the business opportunity emerging from the urge to run away from the origin country. Although men are also victimized in this process, the overwhelming majority of those trafficked people are women and children. From this point of view most of them are teenagers or just little older girls (between 15 and 24 years) according to IOM reports. Most of trafficked women arrive directly in Italy from very specific areas of Nigeria (e.g. the area of Benin City and in general from the South of the Country), for being used in forced labour, domestic servitude, or sexual exploitation. Indeed, the traffic of human beings, especially women and children, has become one of the most rewarding illegal economic activities, currently almost equivalent to drug

traffic and arms smuggling (Salt, 2000). Therefore, the trafficking always involves exploitation and the willingness of the victim to leave the country is almost always obtained through the use of deception, or coercion; indeed, the human being traffic represents a modern form of slavery and an affront to human dignity. From this point of view, the checklist compiled by IOM to recognize victims of trafficking includes following elements:

- Gender: the victims are mostly women
- Age: often young and children aged between 15 and 24 years; however, many victims claim to be adults although they are obviously minor
- Nationality: majority of human traffic are from Nigeria and their origins is especially from Edo State, but also Delta State, Lagos State, Ogun State, Anambra State
- Place of departure;
- Level of Education: normally this level is pretty low with big difficulties even in communications;
- Economic Status: often these victims are belonging to particularly needy families with economic problems;
- Family Status: the victims are often the first daughters of large families;
- Health Status: often the victims have evident physical signs of violence and even torture;
- Personal Attitude & Behaviour;
- Many behavioural problems (e.g. aggression-introversion);
- Normally in a group, these victims are the most subservient and silent
- Self-Description: They claim often to be orphans o They claim often that they have not paid the journey o They are have difficulties in telling their journey, especially in the final part, from Libya to Italy o They often declare that they have to reach a relative (sister or brother) or a friend in Italy or in Europe.

- Migrations & Asylum in Nigeria Case: Although many Nigerians crossing the Mediterranean are undoubtedly in the condition of fleeing from the danger of death or from the exploitation or violence, despite to the Convention for the Protection of Human Rights and Fundamental Freedoms (CE, Rome, 04.11.1950), the recognition rates for asylum and protection are pretty low: less than 5% of Nigerian immigrants get refugee status in Europe and overall about 25% get protection in the various forms provided for by national law.

In modelling the scenarios for Decision Makers on Migration Flows, it is evident that every human being has the inherent right to live and he owns the right to escape from situation where he is threatened by wars, famines, oppressive forms of government; obviously under these extreme conditions menacing life, the resulting flows becomes a survival solution generating almost unstoppable population stream, and unfortunately the world is expected to experience such phenomena until these problems will exist. Nigeria represents from this point of view a big challenge. Europe, as a proximity continent, is obviously a preferred destination for these migration flows, and so it is affected by those. However, the demographics presented above confirms that phenomena have a big inertia and should be not just attributed to temporary crisis situation; especially in the case of Nigeria, the crisis situations result, unfortunately, almost endemic and persistent. By the way this last consideration confirms the necessity to plan actions devoted to address and solve these issues concurrently with management of migration flows in order to win this challenge. The observation of the terrible events and the impressive quantity of drowned people in the Mediterranean Sea represents a dramatic example of the size and complexity of this situation, as well as the impotence of European Union and other major International Organizations and Non- Governmental Organization in dealing effectively with these phenomena. In addition to these elements, the complexity of social and political framework of the EU countries affects the capability to integrate and employ the migrants; economy, security and cultural issues are strongly influencing the public opinion generating opposition movements and social tensions (Lochocki, 2018).

From this point of view, it could be interesting to consider also solutions for Africa based on the similitude of what USA did at the end of World War II, in order to prevent Europeans to immigrate massively in the United States. Borrowing the same perspective, all European Countries should help to find solutions to the problem, even if probably more efforts are expected to be required by those Nations and Corporations that have, or are continuing, to received special economic benefits from the exploitation of the riches of the African continent by aggressive policies. Despite this moral consideration it is evident that for the future the process should be planned and ruled in order to be manageable and sustainable; in addition, Europe should also consider the position and plan of other major players such as China, very active in Africa Continent, USA and Russia in order to succeed in its own global objectives.

These considerations should be the basis to develop the scenario, to model the drivers and degrees of freedom that should be included in the simulation in order to be able to complete experiments useful to support the decision makers.

2.2.4 V&V applied to Nigeria Case study

This research is currently based on reorganizing the previous models and to develop new conceptual representation to reproduce the population dynamics; therefore some preliminary model about flows change due to stochastic factors has been introduced and model by applying discrete event Monte Carlo simulation; in this case, it was carried out a measure of the experimental error due to the pure influence of stochastic factors also in order to apply ANOVA (Analysis of Variance) to the simulator (Donohue 1994); the graph proposed in figure 56 confirm the stability of the simulator and the acceptable confidence model of the preliminary version of the simulator DIES IRAE SOCKS in reproducing the migration flows.

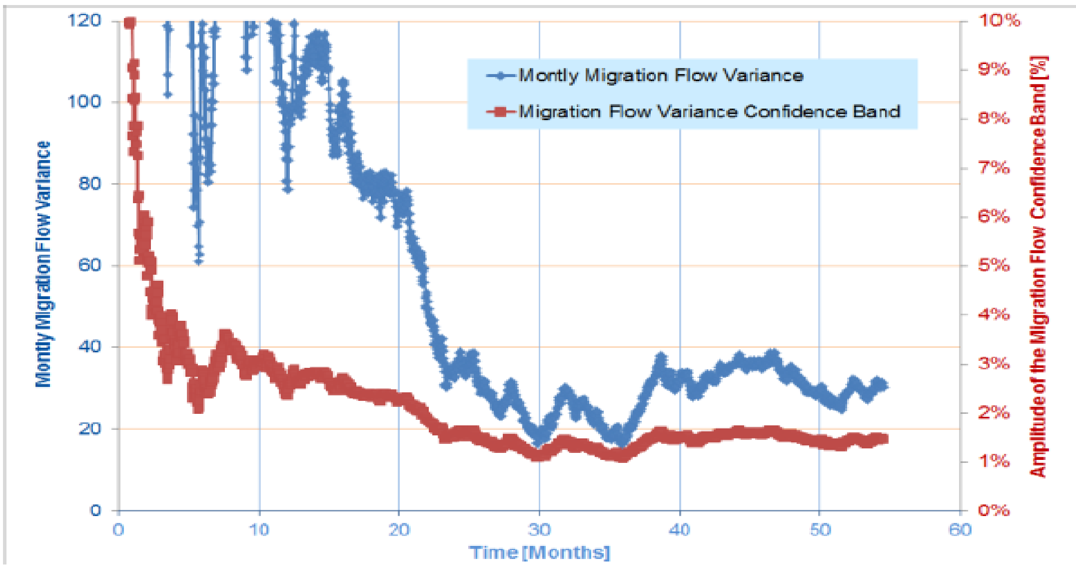


Fig. 56 – ANOVA applied to average migration flow

In the figure proposed, the average monthly flow to Europe since the starting year has been calculated for over 5 years; it is important to state that the predictive capability of the simulator is obviously limited respect complex target functions (e.g. social key performance indexes), therefore it is evident that migration flow quantities could be properly estimated over medium periods.

This paper proposes the development of simulation models of migration flows based on Human Factors and Intelligent Agents; the complexity of the context is pretty hard, therefore previous researches in the field demonstrated the potential of this approach and the obtained results are pretty good. However, this research represents a first step to create scenarios, data set and models to conduct an experimentation where potential actions and policies are suggested in order to provide guidelines and support to decision makers.

2.3 Joint approach to model Hybrid Warfare to support Multiple Players

Hybrid Warfare is demonstrating its impact on vulnerability of the modern society especially related to social networks and innovative technologies, and it is strongly related to many different fields including economy, politics, strategic communications & media, cyber defence, social networks. The players on this game are required to master different techniques and subjects; due to these reasons this paper proposes an integrated approach devoted to be able to combine different models and elements within a simulation framework. The proposal provided by authors describe the model architecture as well as some model examples and an application field used to carry out tests and experimentations.

2.3.1 Introduction

Nowadays the new technologies and social evolution are enhancing the impact of the phenomena that are usually defined as Hybrid Warfare (HW). HW is based on non-linear actions (McCuen,2008; Racz, 2015; Thiele, 2015; JWC, 2015; Cayirci, Bruzzone et al. 2016; Radin, 2017) carried on in terms of discontinuities respect crisis evolution and in terms of actions across the DIMEFIL spectrum. Hybrid Warfare Strategists considers the whole common interconnected comprehensive environment (Cayirci, Bruzzone et al. 2016) as the place where carrying out concurrent actions devoted to achieve desired effect by forcing the opponent to take favourable decisions without the need to be engaged in traditional warfare (Galeotti 2016; Blinka 2017). The hybrid approach has been extensively used in the past (Hoffman 2009; Murray & Mansoor, 2016); indeed, even if there are still concerns about the proper use of the term Hybrid Warfare itself (Van Puyvelde, 2015), it is evident that the current world represents a very promising framework to experiment these techniques in new ways (Cayirci, Bruzzone et al. 2016). In facts the use of modern media and communication channels, directly reaching the population almost without intermediate control, allows to diffuse real and fake news, information and strategic messages that could heavily influence the behaviour of a Nation or an International Organization, as it was impossible just few years ago. A very good example is provided by the case of 2016's USA presidential election, where it was scientifically measured (Enli, 2017) the greater influence of web social networks respect TV media in terms of capability of targeting specific messages on the electors (Bond et al. 2012). It is evident that the use of scientific models able to predict the reactions of populations, as well as that one of Institutions and Organizations, represents a strategic advantage.

This scientific approach makes evident the potential of Modelling and Simulation (M&S) for studying HW and for related Educating & Training (E&T) of the decision makers. Therefore, as anticipated, Hybrid Warfare is based on concurrent actions that evolve based on a not progressive approach in terms of escalation; in HW the actions are characterized by discontinuity in attacking, concurrently, different elements of an opponent such as finance, media, cyberspace, population trustiness, politics (Keeton &McCann, 2005; Bachmann & Gunneriusson, 2014). In a hybrid environment characterized by high operational tempo and driven by acceleration (Di Bella, 2019), the actors are requested to operate on multiple layers, involving experts of the different domains, to maximize the impact of the actions over time; due to these reasons, it is proposed here a joint architecture to address this problem that is based on interoperable simulation and leads to create a common framework for virtual experimentation. An innovative approach has been undertaken by utilizing these concepts and a simulation architecture able to support its implementation; in facts, there are already examples of simulators able to address HW Scenarios where multiple players could introduce their expertise and test hypothesis and settings to play simulation based table top exercises, devoted to acquire expertise and share results (Levis & Elder, 2016).

Indeed, this approach allows to evaluate reliability of available info and data by testing them on realistic virtual scenarios; in this way it becomes possible to finalize studies, comparisons and analyses based on validated and verified common simulation frameworks. In particular, it is proposed to use MS2G (Modelling, interoperable Simulation and Serious Games) as paradigm to develop new intuitive multi-layer environments where different players could interact dynamically (Bruzzone et al. 2014b).

2.3.2 Complexity in Hybrid Warfare

Different kinds of complexity are present in Hybrid Warfare; some are strongly related to the inner difficulty to identify the principia ruling some component as well as to model them (Cayirci, Bruzzone et al.2016); a very good example of that is related to modelling economics as well as rational and emotional processes ruling this framework (Rosser 1999; Bossomaier et al.2000). Therefore, other kinds of complexities are related to the high number of interactions among many entities that affect the system introducing emerging behaviours difficult to understand and predict (Bossomaier, Bruzzone et al. 2009). Obviously among the most complex elements it should be counted the population as well as human factors that is a corner stone in Hybrid Warfare (McCuen 2008; Baker 2015; Di Bella 2015; Lamb 2016). All these aspects result today much more sensitive to HW respect the past especially due to responsiveness and vulnerability of social networks, web applications, mobile solutions and Internet of Things (Hashem et al. 2015; Turban 2015; Larosiliere et al. 2017; Silva et al. 2017).
For instance, it is very interesting today to develop models about the diffusion of real and fake news through social networks and the related trustiness evolution (Bruzzone et al., 2013a). So far, it is crucial to model these elements, and the present research track is focusing on the need to identify and model these multiple complexities and their interactions. It is fundamental to adopt an approach that enables the creation of innovative simulators able to reproduce these scenarios and to carry out virtually defensive and offensive HW actions evaluating their relative impacts.

2.3.3 New vulnerabilities

Today, there is an “explosion” in terms of technological advances and new dependencies of the modern society respect to informatics, social media, satellites, power grid, etc. This aspect made the States and Population much more vulnerable at possible new types of HW attacks with catastrophic impacts (Davis 2015). Therefore, often it is not just necessary to conduct a real attack, but it could be devastating even to diffuse fake news driving fear and dissatisfaction among the population. This concept is much reinforced by the loss of credibility of most institutions or by their latency in reacting to such phenomena; it is sufficient to mention cases such as Iraq (supposed) weapons of mass destruction or the Anti Vaccination campaigns to realize that people do not have that much trustiness versus official Institutions and Organizations (Dadge 2006; Bennett 2016; Kadam 2017). From this point of view, the Internet is a very effective channel able to diffuse so many information and to correlate them in a way that is possible to create consistent big data sets able to saturate the understanding critical capabilities of a large part of the population. In addition, this context is reacting very quickly to the actions; in facts while in case of traditional media (TV, Radio, Newspapers) it was required a lot of time and efforts to diffuse a message, the interactive nature of the web allows the individual to be targeted personally, but also to react actively by investigating and interacting with friends and opinion leaders. Syria Civil War presentation to media is a very good example of this fact (Fisk, 2017) and the “media war” on-going from the different actors with their specific interests are pretty evident to an expert eye as their ineffective approach respect young generations moving on the web that have a different perception (not necessary more correct. The point is that when trustiness is gone, it becomes very hard to recover; in such situation a ruthless, smart player could diffuse easily fake news and reinforce their credibility by properly preparing the web context in advance, for instance posting preliminary info and constructing source and expert credibility. These techniques have been experimented in entertainment industry with success; examples are the promotional campaigns for television serial as “Lost” and “District 9” (Jones, 2007; Kapstein, 2014).

Coming back to the Hybrid Warfare, it results evident that attacks does not have to be kinetic, but they could be just carried out on the media layer: just think on what could happened if it is diffused fear about a pandemic among the population (e.g. health care structure saturation, transportation and service shutdowns); in the USA, this was experienced with the campaign on Anthrax letter (Nunn, 2007). The government however, in 2001, deemed on that regard to run an exercise to address the issue (code name Dark Winter) at John Hopkins University Centre for Civilian Biodefense Strategies (https://www.centerforhealthsecurity.org/our-work/events-archive/2001_dark-winter/).

From another point of view, cyber-attacks could result able to crush the power grid for some time (e.g. fridges and telephone not working, phones disabled, ATM and credit card network down, computers not available etc.) or in obscuring the satellites (e.g. GPS not working, communications breakdown), which represent just a few dramatic examples of the situation (Ottis 2008; Kallberg 2016). In facts, it is expected that in future the different actions characterizing hybrid warfare will be conducted in strict synergy to maximize their impacts on forcing the opponent to accept the conditions imposed by the attackers, in order to reduce the damages and maintain stable his society and infrastructures. So in the near future cyber and media attacks could be combined with attacks on other PMESII-PT layers and it could be necessary to create models able to reproduce these combined phenomena. In such kind of scenarios, it is very important to be ready to face the possible critical events in order to minimize the damages and to guarantee the keep control of the situation, solving the problems as fast as possible. Furthermore, the multitude and variety of the possible actions that could be carried out over the different layers represents a big challenge that requires multiple models and skills to be connected together.

2.3.4 Multilayer and multiplayer architecture

Obviously the difficulties in modelling all the different elements, the uncertainty affecting these contexts, as well as the mutual influence of many factors, suggest the development of new interoperable simulation solutions to support decision makers as well as experts. Indeed, the use of simulation allows to obtain results that are of great benefits in the analyses of these phenomena by recreating possible scenarios and evaluating risks and vulnerabilities. By this approach it becomes possible to investigate the influence of alternative hypotheses and boundary conditions respect to scenario evolution and to evaluate different approaches. As it emerged in studies in this sector the innovation, creativity, as well as previous experiences, have a crucial role in the study of Hybrid Warfare. So, any instrument able to share this kind of knowledge will represent a strategic advantage; in addition to this fact, the synergy among users, experts and simulation scientists guarantee to advance the researches and understanding of HW as well as to improve model capabilities in addressing such complex subjects. In general, it is evident that this context is a complex system and that simulation is the prime methodology to deal with it, however it is quite difficult and hard to maintain the development of a large standalone simulation system. In addition, the very eclectic nature of HW context requires to engage many different SME that are often not familiar with M&S techniques nor with HW; so in order to develop and validate the models it is necessary to create an environment that should be able to be intuitive and direct in presenting the scenario evolution to all these different subjects (Bruzzone et al.2017b). In this framework the use of models and technologies to develop effective capabilities, new doctrines and to develop valuable training programs is fundamental; in particular, the proposed approach is based on the idea to create a mosaic made by interoperable models able to be combined as tiles to cover an extensive part of the Hybrid Warfare, and even to propose to users an interactive and intuitive environment based on modern Serious Games (Raybourn 2012; Bruzzone et al.2014a, 2014b).

2.3.5 A HLA Mosaic Architecture

The metaphor adopted for this simulation is the "mosaic": a mosaic where each component or layer, such as power grid or web social networks, serves as a tile able to interoperate with other ones. So it is evident that the risk in this approach is to be unable to play the game if some tile is missed. In order to avoid this problem, meta-models should be adopted to cover each subject and substituting missing tile in order to be able to finalize the execution of the simulation in all conditions (Bruzzone et al. 2009; Barton 2015). Meta-models should serve as simplified representations of specific domains; each of them should use the same objects, attributes and interaction adopted by the overall simulation in order to be interchangeable within the interoperable federation of simulators.

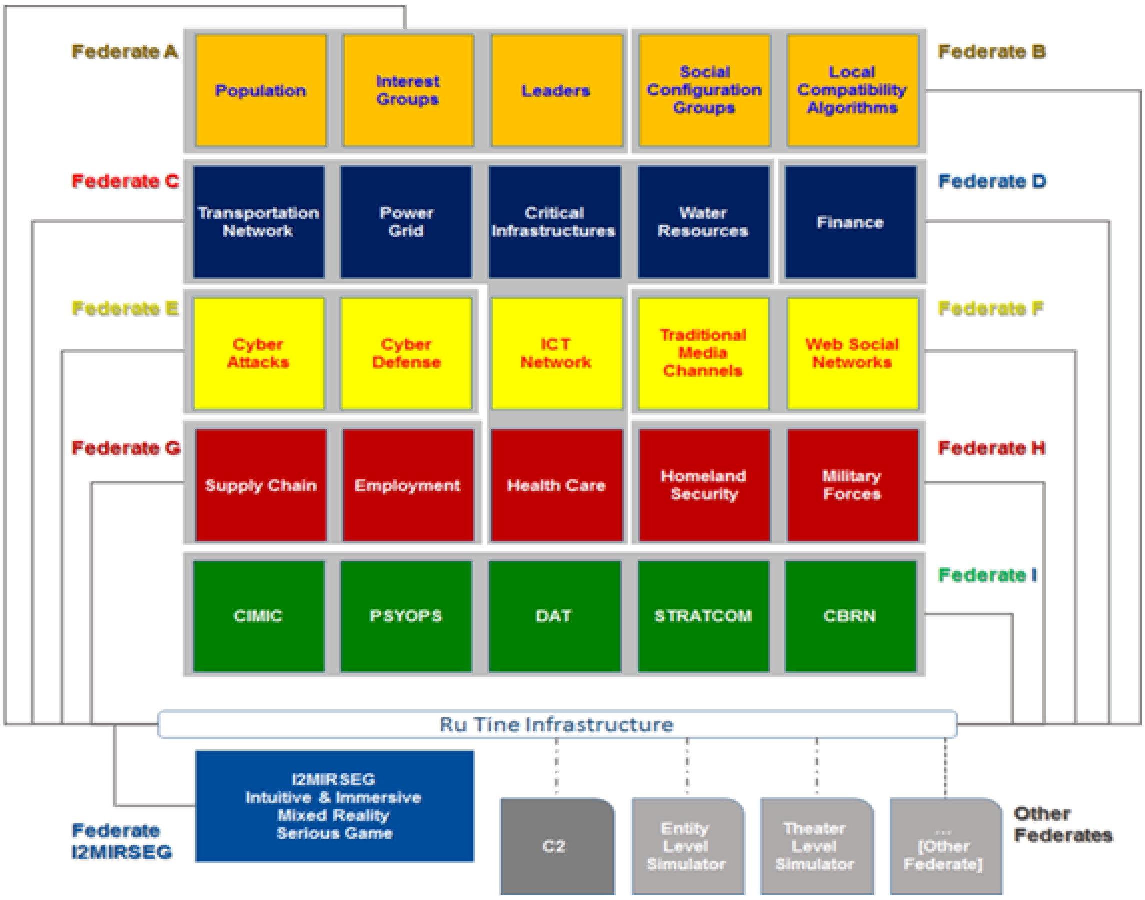


Figure 57 - A "mosaic" HLA Federation

This approach enables to adopt different meta-models, more or less detailed, based on the need or, even, to substitute them by sophisticated models or simulator when required. A very important element of this approach is to guarantee the possibility to integrate also other simulators, already available, as well as real equipment in use, to present the situation to decision makers in a familiar way. Due to these reasons the it is suggested to define as interoperability requirement the adoption of IEEE 1516-2010 "evolved" that is the updated version of HLA standard (High Level Architecture). In order to be able to run a such complex federation, it is fundamental to automate the execution of the different federates; in facts the use of man-in-the-loop on this subject will result in requiring many simulation operators connected to run a single experiment and it will increase drastically the execution time, probably requiring to operate real-time. In addition to these elements, such traditional approach introduces also subjective components due to the human player status that could compromise the validity of experimental campaigns. Vice-versa, in this context it is fundamental to be able to run fast time simulations in large number to create a virtual expertise over this new subject; this could be achieved by introducing IA (intelligent agents) driving the simulation (Bruzzone 2013d). Therefore, the SME Players are still a fundamental element of this simulation, but they need to act based on the concept of the man-on the-loop, supervising the operations without getting lost in details. Indeed, in this case, the players are expected to supervise the simulation execution, while it is running fast time, just to assign high level tasks to the IAs as well as to introduce general attribute changes. Due to these reasons, it is necessary to include in the models, advanced IAs able to deal autonomously with the scenario evolution based on their own perceptions and their specific objectives. Simulation Team accumulated large expertise in this field by using the IA-CGF (Intelligent Agents Computer Generated Forces) in several of these subjects such as PSYOPS (PSYSOP Simulation, Psychological and cultural Simulation Of Population), CIMIC (CAPRICORN Federation, CIMIC And Planning Research In Complex Operational Realistic Network), Strategic Decision Making (SIMCJOH Federation, Simulation of Multi Coalition Joint Operations involving Human Modelling), etc. (Bruzzone et al. 2009; Mastrorosa et al. 2012; Di Bella 2015). Indeed, the impressive IA-CGF capabilities in human behaviour modelling to support population simulation, as well as their native HLA structure, suggest to adopt them as core engine in this application; therefore, the open architecture of the proposed federation guarantee the integration of even other tools and solutions (Bruzzone & Sokolowski, 2012). Obviously it is fundamental, from this point of view, to provide users with an understandable picture of the scenario evolution, so it is evident that an additional and very important element of this federation should be an Intuitive & Immersive Mixed Reality Serious Game (I2MIRSEG). This module is devoted to create a synthetic environment intuitive for the different players representing the scenario dynamically evolving. Most players are expected to evaluate and interact directly with the I2MIRSEG federate and to get many information through a Mixed Reality (MR) interface presenting terrain and entities as well as additional information. In this MR representation, the overall situation could rely on different model tiles embedded in multiple federates and open to interact with external simulators. So, by this approach the overall simulation is a federation while the tiles will become parts of the federates, each of them will have objects with attributes and interactions to be shared within the federation to be used effectively. It should be considered the fact the many of the domains to be covered could have already expertise subdivided in different heterogeneous pieces and framed in different formats, including not digital or computerized models.

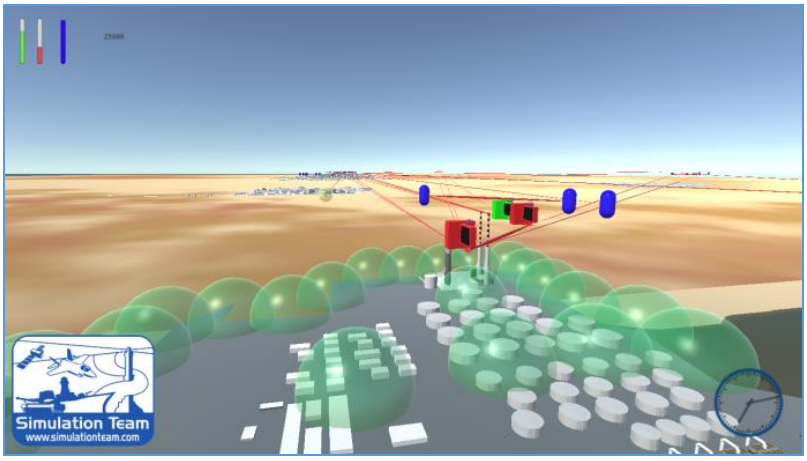


Fig.58 – I2MIRSEG Augmented Representation in T-REX Simulator

These aspects suggest to proceed progressively in creating the meta-models corresponding to the different tiles by implementing the existing knowledge into them. Even very simplified models should be adopted when necessary to guarantee consistency, usability and maintainability. Indeed, the data availability could result sometime critical to finalize validation and verification as well as to guarantee the capability to keep updated the models (Amico et al. 2000). For each tile, it should be defined the set of objects representing the key elements as well as their attributes and the interactions to be adopted to modify them. For instance, for the federate incorporating the cyber-tiles the following objects could be included with relative attributes:

- Cyber Defence:
  - Defensive Team Resources
  - Defensive Team Responsiveness
  - Defensive Team Efficiency
  - Defensive Team Effectiveness
  - Anti Virus Diffusion
  - Anti Virus Resilience
  - Anti Virus Level

- Cyber Attack:
    - Attack Team Resources
    - Attack Team Responsiveness
    - Attack Team Efficiency
    - Attack Team Effectiveness
    - Virus Dynamism
    - Virus Initial Injection
    - Virus Infectivity
    - Virus Resilience
    - Virus Level

Specific interactions should be activated to allow to increase or decrease each of the scalable variable attributes by defining impact, lead time and duration; so for instance if it is decided to increase the number of the defensive team resources it could be used the interaction: *modify_defensive_team_resources(dm, lt, dt)*
dm: change in number of defensive resources
lt: lead time required to start the to increase the resources
dt: delta time required to complete the increase on the resources
In similar way, interactions should be used to change the level of cyber assets to be targeted by a virus or the initial injections of the virus. The players in this game expected to interact with the scenario through their specific tools and simulators as well as through the common I2MIRSEG covering different domains; for instance, in the proposed case, it is expected to engage SME with different operational issues, including among the others:

- STRATCOM
- CIMIC
- PSYOPS
- Cyber Defence
- Defence Against Terrorism (DAT)

2.3.6 T-REX: hybrid threats in multi-layer scenarios

In order to conduct the experimentation, it is defined a scenario derived from previous researches carried out on these subjects, employing the T-REX Simulator (Bruzzone et al. 2013b; 2016a; 2017d); it involves a region (in a desert environment, so the water treatment facilities result particularly critical for the population), with different towns where a threat network operates. In this mission environment there is the presence of several interconnected critical infrastructures, i.e. power grid, water resources and oil supply chain, that the terrorist/threat network are supposed exploit, acting on different ways: cyber-attacks, use of small drones against critical infrastructures, coordinated attacks on media.

One hypothesis assumes that the threat consists in a wing of small drone quadcopters equipped as IED in order to deliver explosives, in coordination with a cyber-attack, which has the objective of introducing viruses acting on data integrity to disable the defensive capabilities of the critical infrastructure compound. At the same time the threat network could diffuse over different media channels and web social networks real and fake news about the critical situation of the region and the vulnerabilities, spreading fear, mistrust and suspicion among the population. In any case, even though the drone attack on the critical infrastructure hasn't been successful, the threat network can leverage on the media network corruption in order to display a massive damage; in case of successful attack, this fear will be further reinforced by additional media material creating a direct impact on water and oil distribution as well as on power availability in the houses.

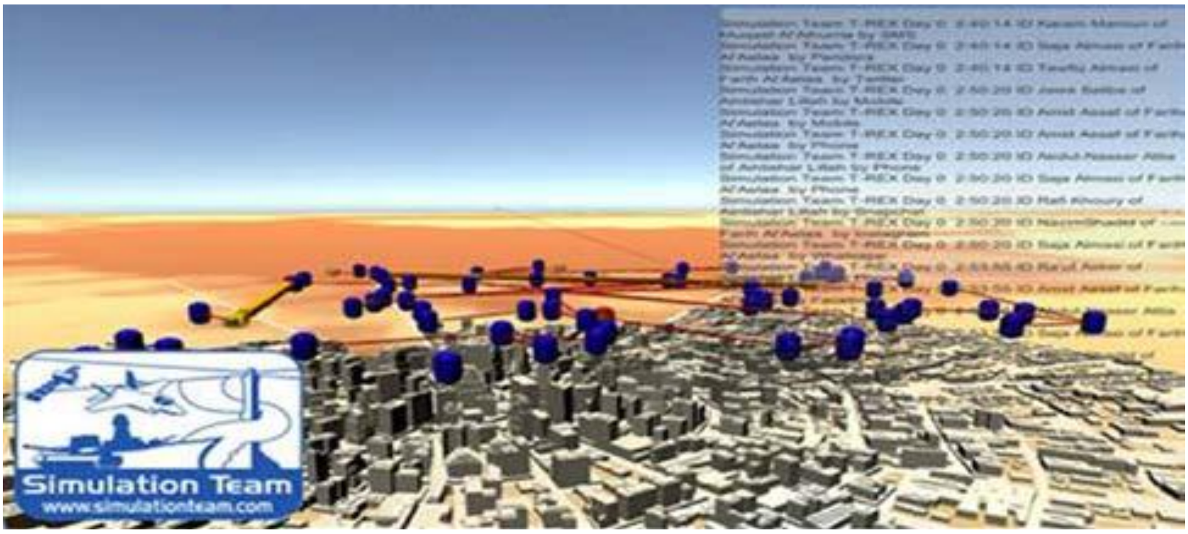


Fig. 59 - T-Rex: dynamic evolution of threats

This is an example where different actions could be applied to create pressure on the opponent without forcing the situation to move into an armed conflict (Cayirci, Bruzzone et al. 2016b), even though the resources used by the threat network and its attack coordination capabilities makes it evident that the aggressor is much more than a group of terrorists.

In this scenario, the IA-CGF are used to model the population that act autonomously based on their predefined life cycle (e.g. sleep, wake up, breakfast, moving to work, work, pause for lunch, work, moving back home, relax, having dinner, entertainment) in regular conditions and react to the crisis; in facts, for the agents the life cycle is not fixed and in case of perceiving critical events or changes in boundary conditions they react based on their perception and their own characteristics including psychological factors, human behaviour modifiers and previous experience. The adopted model has been integrated with the IA-CGF, therefore the IAs reproduce not only the people, but also their social networks and the corresponding interest groups (e.g. a leader, a religion, a social class, a generation, an ethnic group, etc.) to guarantee a proper representation of the social dynamics (Bruzzone 2013c). In this case, in addition to population models, it is present also an Information and Communication Technology (ICT) network mapping the Internet of Things (IoT) interconnected, and for each of these element and each of the links are defined variables mapping the levels of confidentiality, availability and integrity. These variables could be attacked by virus or other cyber actions, as well as restored by automated defences or cyber defensive resources; the events on the cyber layer interoperate with that ones on the physical space including power grid, water resources, strategic communications, etc. The threat network is hidden among the population and false alarms are generated as well as spill of information captured by HUMINT or ELINT, web watching and other intelligence resources. In facts, threat network members have their multiple operational statuses including dormant, stand by, planning, preparing, acting and they move on the terrain as the regular people; they could be hidden or detected and/or tracked and often they interact with regular people as well as with the ICT network based on their access capabilities.

For the proposed scenario, the critical infrastructures are concentrated into a “safe” compound facing the sea and protected by different automated and traditional security systems, coordinated by a control room: the autonomous systems include

UAV and USV available for patrolling the area and investigated on suspects in case of alerts, in addition the area is protected by an air defence system, EW capabilities, surveillance systems & cameras and finally, the traditional security guards. In facts specific IAs are in charge of controlling these entities and units that interoperate autonomously in the mission environment based on high level tasks. As anticipated, the IEDs used by the threat network are small drone-quadcopters operating individually or as a swarm, and potentially directed by different control systems (e.g. prefixed GPS coordinates, inertial system). The simulation operates fast time and real time, making possible to slow down or accelerate execution speed by the user, to better understand the dynamics of the events.

As I2MIRSEG support it is adopted the SPIDER (Simulation Practical Immersive Dynamic Environment for Reengineering), a virtual immersive interactive interoperable cube where virtual and augmented reality are integrated to propose the simulation to the user. Indeed, the SPIDER has been developed as CAVE (Cave Automatic Virtual Environment) by the Simulation Team to be interoperable through HLA with all the IACGF NCF (Non-Conventional Framework) and it represents an effective solution to achieve a clear operational picture of the whole situation (Bruzzone et al. 2016b). This interactive CAVE allows also to investigate details on specific assets, entities or elements of the networks by touch screen technologies as proposed in figure below.

Fig.60 - SPIDER CAVE used as I2MIRSEG Solution

The immersive IA-CGF NCF used for this simulation could also propose to users a virtual representation of the cyberspace, augmented by presenting the dynamic evolution of integrity, availability and confidentiality characteristics of each element, as proposed in figure 61.

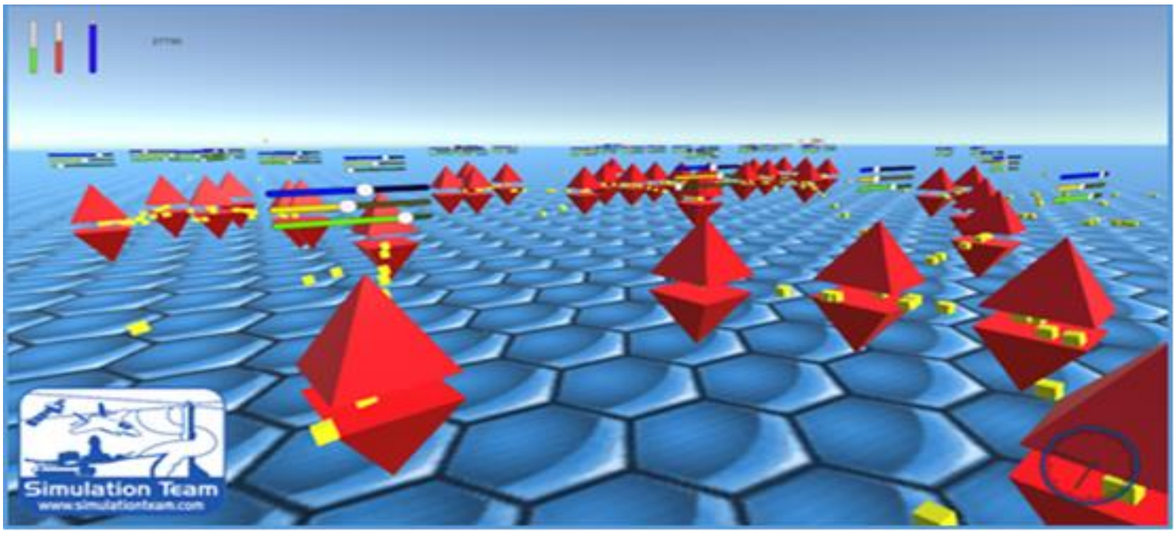


Fig. 61 T-REX: Cyberspace representation with Node Attributes

2.3.7 Dynamic experimentation

The test scenario to support dynamic VV&T (Verification, Validation and Testing) considering the following general independent variables:

A Virus Resilience

B Virus Infectivity

C Anti-Virus Diffusion

D Anti-Virus Share

Last parameters represent the ratio between strong and regular Anti-Virus installed on the ICT resources.

The target functions included three different factors:

• CPT (Cyber Penetration Time): Time required to compromise the Critical Infrastructure ICT Network

• CPV (Combined Physical Vulnerability): Number of Critical Infrastructures disable due to the combined Cyber and Physical Attack

• PTD (Population Terror Diffusion): Diffusion of the terror among the population due to the combined media and real attack to water and power resources

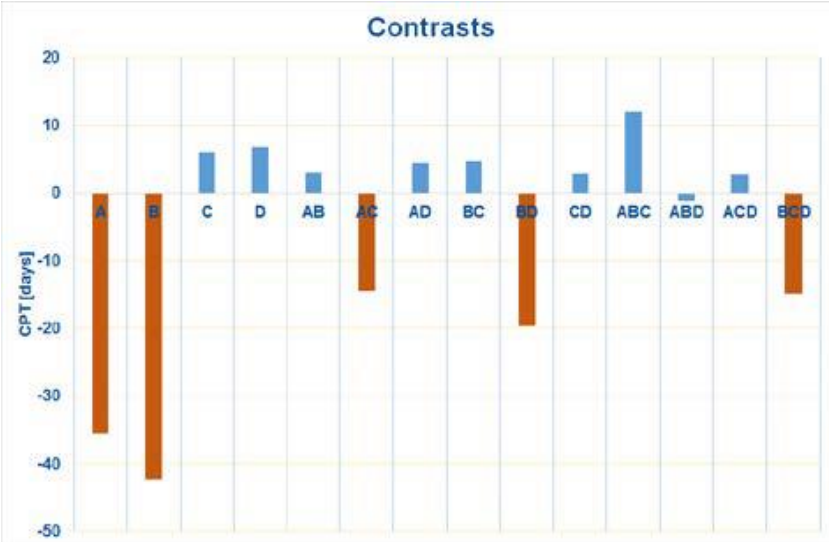


Fig. 62 T-Rex Sensitivity Analysis

The experimental error of these target has been investigated through the temporal analysis of the Mean Square Pure Error while a CCD (Central Composite Design) has been experimented to finalize the sensitivity analysis (Montgomery 2008). In figure 62, it is proposed the sensitivity analysis expressed in terms of contrasts respect CPT target function; in this case the values above zero represent direct influence of the corresponding variable on the output while the others result to have a negative proportional influence. The analysis confirms the consistency of the overall model; the high number of combined factors influencing the target functions confirms the complexity of the problem.

In conclusion, it has been proposed a joint approach for creating a synthetic environment able to simulate Hybrid Warfare scenarios. The case proposed represent a first example among many possible examples and the related preliminary experimentation confirmed the potential of this approach and the validity of the models. The future goal of this initiative is to create a joint team of top experts able to support these developments as well as to continue to add new tiles to this simulation frameworks including both new simulators and legacy systems.

2.4 Time management in Hybrid Warfare: rise of Strategic Engineering

Time, in its physical dimension and social perception, appear nowadays often neglected in Military Operations because of other overwhelming concerns, such as firepower and geometry of the battlefield; instead we would like to highlight that time is a critical concern as well for a military commander, from tactic to strategic levels. “Commodity of Warfighting is Time”, remarked Scott Swift (ret. USN Adm) during the panel discussion at DARPA’s sixty anniversary in September 2018 (https://www.youtube.com/watch?v=33VAnIEjDgk) .

This paragraph reviews, based on current operations, some of the critical issues to be addressed in order to develop a strategic capability based on innovative technologies; the aspect of time and timing is outlined as one of the main factors that lead to success as it is well known not only in military operations, but even in the everyday life.

It is evident that the approach proposed based on introducing science and models into this context emerges as one of the crucial elements to succeed, as well as the necessity to let decision makers and experts to interact within common immersive and intuitive interactive simulation frameworks. These considerations suggest the need to develop *Strategic Engineering* as a new discipline addressing these issues and preparing new generations of decision makers and scientists. Indeed, today technologies sound as great enablers; however, it is very important to decide how to use and to shape new solutions, and thus evaluating up-to-date situations as well as consolidated knowledge to identify a need for developing new capabilities based on quantitative approaches.

Sun Tzu define the importance of completing proper quantitative analysis by saying that “the general who wins a battle makes many calculations in his temple ere the battle is fought. The general who loses a battle makes, but few calculations beforehand. Thus do many calculations lead to victory, and few calculations to defeat”.

It is evident that today, the calculation capability mentioned by Sun Tzu relies on advanced modelling and simulation used to support decisions as well as on data science and smart techniques to support decisions. These aspects are obviously fundamental in war, but even in other mission environments as well as in industrial

business and it is fundamental to guarantee access to this capability by preparing the "calculation" systems, the people that have to operate and feed them as well as the decision makers that should be able to get benefits from their usage.
In the next paragraphs it is proposed an approach to develop new capabilities in strategic engineering of Military Operations Other Than War (MOOTW), in which hybrid and asymmetric threats are present. In facts one of the scarcest resource in developing strategies is often the Time, and we consider it in its wide definition, including physical and human phenomena that affect execution of plans. It is evident that Time could often make difference between success and failure respect strategy development.

2.4.1 Fight by the minutes: Time and the Art of War, Robert Leonhard, 1994-2017

"I act not by laws, but by minutes." - Alexander Suvorov (1729-1800).

In this paragraph, we will frame the phenomena of Hybrid Warfare inside the remarkable theoretic work of Lieutenant Colonel (Rtd) US Army R. Leonhard, which introduces his book **"***Fight by the minutes: Time and the Art of War"* written in 1994, with the phrase: "*My thesis is simple: the most effective way to perceive, interpret, and plan military operations is in terms of time, rather than space*". There is no doubt that, according to the author, that traditional military history has dealt with the subject of warfare just from a spatial perspective, a three-dimensional box shaped by length, width, height. But there is a fourth dimension in warfare, time. From such perspective, addressing the dimension of time allow to understand the four temporal characteristics of Warfare: duration, frequency, sequence, and opportunity, and to master at a nation's advantage. If that holds true, the corollary is that adopting a temporal perspective in conflict management can make the difference in warfare. Such innovative contribution ideally reconnects his thought with a remarkable military leader of the past, Napoleon, who was always busy at mastering the time while denying such scarce resource to his adversaries on the battlefields. *"The loss of time is irreparable, in war...Space you can recover…time never"*, Napoleon once asserted.

In the Preface to 2nd edition (July 2017), Leonhard highlight that "Time factors remain largely unexplored". More than ever, duration, frequency, sequence, and opportunity aspects continue to frame war, peace, and the murky middle-ground that some have named "the grey zone"; more recently Thiele (2015) expressed that "grey is the new colour of war", this because although in the past irregular warfare have been often used due to the weakness of the actor with no sufficient means to engage using conventional warfare, future brings challenges where hybrid warfare is used not only by weak states and none-state entities, but also by powerful and capable states.

According to Leonhard, in order for the US to meet their strategic obligations, it is necessary to compensate for decreasing mass (because of the decline of the US military presence oversea since the end of cold war) with increased velocity: Strategists then are challenged by the problem of accelerating the movement of mass over time. From this perspective, the advantages in terms of time savings derive in peace time from good planning and exercising (see Figure 63).

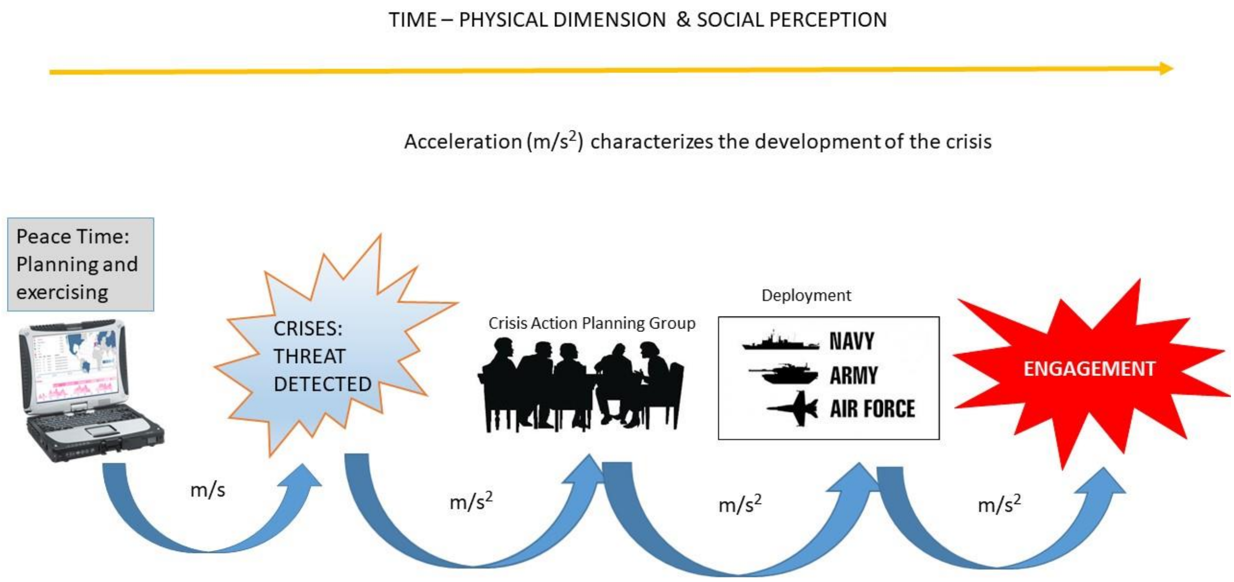


Figure 63 - Timeline of Crisis: acceleration

However, once a crisis has sparkled, acceleration (m/s^2) express how fast a unit or a system can change speed, direction, verse. Again, a high capacity for acceleration is valuable to a commander in war, but it drains rapidly scarce resources (such as training time, well-equipped staffs, technological dominance, etc.). Also, acceleration and mass have an inverse relationship: the greater the mass, the less the acceleration and vice-versa according to Leonhard. The two major military operations carried out in the last 20 years by US Army - Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF) - have witnessed a high capacity of “acceleration” (understood as the capacity to plan and execute a projection of large combined forces across land, sea and air), followed however by a sort of deceleration in terms of decreased mass and speed of execution. From this perspective then, while the timeline of crisis is driven by acceleration ((m/s^2), the timeline of decommissioning is driven by an almost endless deceleration ($-m/s^2$) (fig.64, Di Bella, *Strategic Engineering for Defence and Homeland Security*, Strategos Workshop, Rome 16th September 2019).

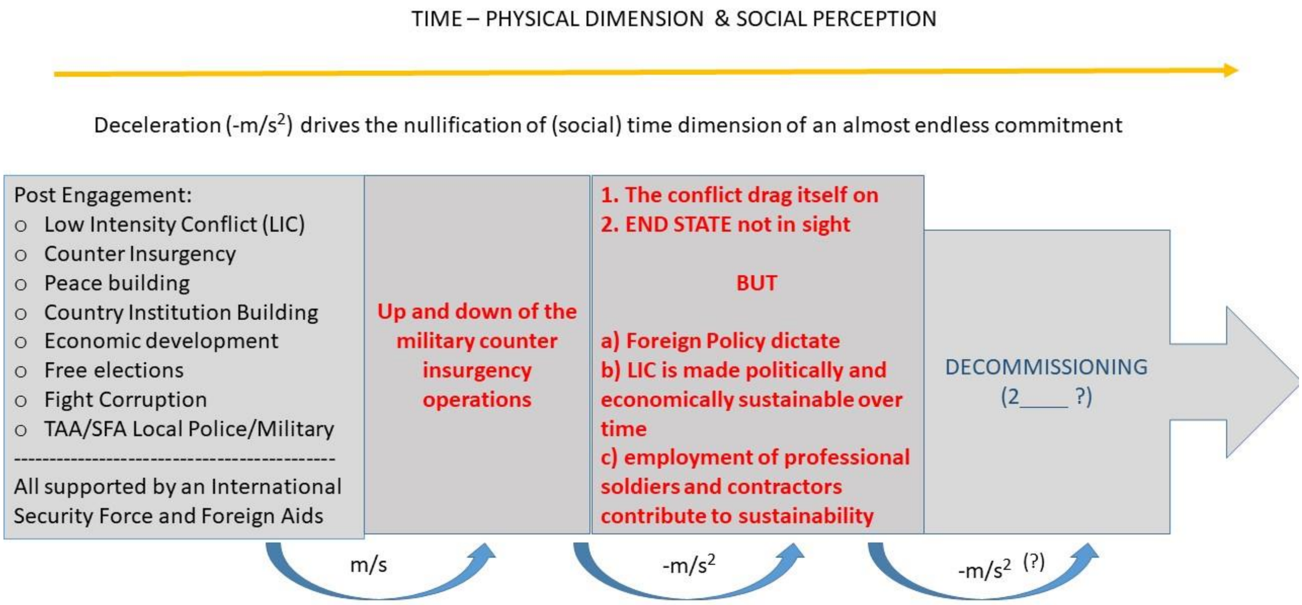


Fig. 64 - Timeline of decommissioning: deceleration

In order to understand the figure above, it is necessary to inquiry about the meaning of END STATE. It represents, according to the US (DoD JP3-0), “The set of required conditions that defines achievement of the Commander’s objectives”; so the successful completion of any military operation must be matched against it, as defined in campaign plan and eventually achieved during the campaign’s execution. End State, kept secret or not, looks like then pretty militarily in its essence, but instead it is very politic, since it defines the set of conditions to declare that the military commitment is not necessary anymore (decommission of the force). Years of campaign without the achievement of the desired End State can result in the change of the End State itself into a new one and so on, for an un-precise numbers of years, assuming that the intervening country can afford politically, socially, economically and military such exhausting struggle. So, any "conflict" engineering should take into account this inherent limit, which not known at the beginning of the engagement, but if disregarded can bring serious consequences (Di Bella, 2019). For the above considerations is imperative then, for the professional military but also for the civilian policy makers and for those employed in Defence apparatus as scientists, engineers, administrative staff etc. - to first comprehend and then master the temporal characteristics of warfare.

Conflicts, as we have seen, both in their pure military but also hybrid form, have a duration. That is, they have a beginning and an ending, often not well defined; this is very important mainly for the civil and military actors called to react, identifying, in case of a Hybrid Threats, if attacks have escalated into an open aggression or are kept under the threshold without triggering the UN Chapter VII provisions (Cayirci, Bruzzone, et al. 2016). However, the duration of a war/hybrid confrontation is managed by the top political level of a country, and as well by the military establishment, the last though a function that describes how well that war is carried out by the troops. In addition to that, there are a number of independent variables—some obvious, some hastily reduced to nuances in order to over simplify the issue, and some even unknown at the beginning —whose product determine the duration of a war.

It makes sense then following statement of Von Clausewitz: *"Both belligerents need time; the question is...which of the two can expect to derive special advantages from it".* Mao Tse Tung in 1937 in his book *Guerrilla Warfare,* commenting about the conduct of operations during Chinese Civil War, quoted: *"Why a protracted war? "The enemy is strong and we are weak, and the danger of subjugation is there. But... the enemy's advantage can be reduced and his shortcomings aggravated by our efforts. On the other hand, our advantages can be enhanced and our shortcomings remedied by our efforts. Hence, we can win final victory and avert subjugation, while the enemy will ultimately be defeated".* And it was so!

However, duration brings as well attrition, exhaustion, and capitalizing on the recent history it is clear that the more a war drag itself on, the more it will capable to unleash grave consequences to both victor and vanquished. Wars that last longer than expected challenge constitutions, destroy domestic harmony, and cause governments to fall; World War I, the Great War, it is a clear example (four empires vanished: Austrian, German, Turkish and Russian, leaving back enough embers to ignite a bigger fire). But as the statesman and commander contemplate the factors leading to duration, it is likewise imperative that they remember the consequences of it for the armed forces, the state, the economy, and the people. Indeed, in Western Countries we are taught – and we were used to thought - that a war has a beginning and end, marked by declaration of war and armistice/peace treaty. However, contemporary dimension of conflicts, starting from LIC, MOOTW, PKO, Proxy Wars and finally Hybrid Warfare often blurs into something not clear and which does not belong to the obsolete categories of War and Peace, at least as they were intended and categorized until the XIX century. The definition of Low Intensity Conflict (LIC) is then very interesting for our discourse: LIC it is defined as "A political-military confrontation between contending states or groups below conventional war and above the routine, peaceful competition among states. It frequently involves protracted struggles of competing principles and ideologies. Low intensity conflict ranges from subversion to the use of armed force" (Leonhard, 1997). But, as Leonhard promptly warns, *"Low Intensity Conflicts must not be translated into Low Importance Conflict"*. According to US doctrine, LIC breaks down into four broad categories: insurgency/counterinsurgency, peacekeeping, combatting terrorism, and peacetime contingency operations. Insurgency warfare pits unconventional, usually well-organized military/political groups against an established state's government, police, and armed forces. Peacekeeping operations (PKO) involves the positioning of a neutral (usually multinational) armed force between two states or factions in order to lessen the chance of conflict (the typical UN Mission, starting from UNTSO - Unites Nations Truce Supervision Organization established in 1948). Combatting terrorism is aimed at preventing terrorist attacks (i.e., antiterrorism), and reacting to terrorist attacks (i.e., counterterrorism). Finally, PCO, Peacetime Contingency Operations (Leonhard, 1994-2017). In this contest, in 1993 the US Field Manual 100- 5 introduced a new army term to address the problem: Operations Other Than War (OOTW). Although not exactly synonymous with LIC, OOTW certainly comes closer to addressing the myriad endeavours of today's army.

In conclusion of his work, Leonhard states that *"At each level of conflict, from the technical to the strategic, a temporal perspective will reveal new challenges, new opportunities. My hope is that interested students of war, both in uniform and out, will glance at their watches and get to work.* Leonhard clearly calls for innovation, indeed in a very sober as much as vibrant style: "*Armies don't innovate; people innovate. The single most important quality in a professional military officer is the ability to innovate. In an age of increased technological advancement and socio-political upheaval, the number of transitions in military art and science will multiply, with the result that in the span of an officer's career warfare will undergo several dramatic changes. The failure of the officer corps to keep up with change can result in national disaster. But how can a military establishment—by its very nature a conservative establishment—systematically and consistently train its officers to innovate?*" (Leonhard, 1994-2017). The question posed by Leonhard has not been answered yet; however, the author believes that Modelling and Simulation tools and technique can represent the safe "tank" where innovative and advanced technical solutions can be tested, exploiting the advantage of doing it in a synthetic environment.

2.4.2 Models for supporting strategies

The main goal of this paragraph is to consider the issues related to Time within different kinds of operations with special attention to Military Operations Other Than War (MOOTW) and to consider it respect other Measures of Merits (MoM). From this point of view, it is interesting to consider the potential of a new emerging discipline such as Strategic Engineering in supporting achievements of strategic goals respect existing risks and stochastic factors, especially into unusual mission environments such international mission, asymmetric or hybrid warfare. It is important to outline that this context have been already investigate by the authors in terms of creating simulation solutions able to support analysis as well as new doctrine development respect complex mission environments (Bruzzone et al.2016a); these results have been presented both to Nations and NATO and resulted a successful example of models that could be effectively used for creating a Strategic Engineering Capability. The T-REX Simulator operating from an immersive interactive interoperable solution developed by Simulation Team is

proposed to allow analyst to investigate a complex scenario involving threat networks population behaviour, cyber warfare, critical infrastructures (i.e. power grid, oil resources, water resources), autonomous systems on both side.
In this sense the authors participated in experimentation of innovative solutions based on new paradigm MS2G (Modelling, interoperable Simulation and Serious Games) devoted to support Commander and his staff in Strategic Decision Making respect SIMCJOH Project (Di Bella 2015). Figure 65 propose the example on how cooperative decision making is carried out immersed - with the employment of SPIDER- in the scenario dynamics by interacting with the simulator and population behaviour, as well as with the virtual humans representing Commander's staff (Bruzzone et al. 2015b).

Fig. 65 – Cooperation decision making in SIMCJOH

2.4.3 Strategy: long vs short term achievements in Capricorn simulation

As starting point, it could be interesting to remind the definition of Strategy; the word derives etymologically from Greek and results from combining στρατός (army) and ἄγω (leading); indeed, based on classic definitions, Strategy relies on the capability to develop effective plans able to achieve success in challenging situations such as business, politics, war, etc. Looking back to quotes from the past a very good definition is provided by General Jomini in his "Prècis de l'Art de la

Guerre" (1838): ""La Stratégie est l'art de bien diriger" (Strategy is the art of well leading"); Carl von Clausewitz in *Der Krieg* (1832) wrote that "We need a philosophy of Strategy that contains the seeds of its constant rejuvenation, a way to chart strategy in an unstable environment". Now the necessity to develop a conceptual approach and methodologies to continuously control strategy evolution respect a very dynamic and unstable environment, makes evident the actuality of this consideration.

If we look to the words of one of the major text in strategic planning, *Militarische Werke* (Von Moltke, 1871), it is clearly outlined the challenge to keep plan up dated respect evolving situation and the need to proper develop this capability: "No plan of operations extends with any certainty beyond the first contact with the main hostile force". In addition to hostile force dynamics, it should be even considering the difference on mission environments requiring specific approaches and avoiding possibility to generalize single case. From such perspective the Russian Commander (and professor at the military academy) Aleksandr Svechin (soon after victim of the Stalin's Great Purges), wrote in his book on Strategy in 1927 that "*it is extraordinarily hard to predict the conditions of war. For each war it is necessary to work out a particular line for its strategic conduct. Each war is a unique case, demanding the establishment of a particular logic and not the application of some template".*

So, the importance of Strategy was known and concepts formalized since centuries ago; however, it seems that nowadays there are problems to apply such knowledge to current operations. For instance, many modern conflicts result into a mess because of the non-application of strategic knowledge: French Indochina, Korea, Vietnam, Gulf Wars (Betts 1978, Mueller & Mueller 1993; Summers 2009; Pauly 2017), while the standoff in Iraq and Afghanistan are more recent examples. From this point of view, even humanitarian operations and large plan often fail in many contexts, even related to small regions when resource applied appear to be huge (Muchemi 2017; Bruzzone et al., 2017d). To many, the "apparent" failures and difficulties into achieving strategic goals are related to the real complexity of the problems; this topic is even more popular nowadays, in a period where political and cultural movements, currently defined as "populist", apply severe simplifications often without strong foundations, in some way emotionally reacting to partial/total failure of strategic management carried out over years by Institutions and qualified

Experts. Currently as reaction against this attitude, it is becoming very popular among so called “experts” the sentence “complex problems have simple, easy to understand wrong answers”. Now, this absolutist statements are currently promoted by opponents of populism reacting exactly on the same mood, in facts such assumption sounds questionable as “involution” of a much more acceptable sentence “we should be careful about simple solutions to complex problems” (Statell, 2014). Despite author’s personal point of view and the evidence that we need good capabilities and skills to solve problems, it is important to consider that thinking back to history, we can find many cases where simple solutions solved pretty complex problems, at the price however to upturn cultural and social orthodoxy; among the cases, the Gordian Knot (solved by Alexander with a single slash of his sword), which represents a metaphor for an intractable problem.

This consideration should allow readers to reject all polarized approaches such as Black/White, or Simple/Complex, but to apply lateral thinking realizing that things need to be analysed considering their specific nature and characteristics; nowadays conflicts (Hybrid Warfare the most), carried out across DIMEFIL/PMESII_PT spectrum/vectors, are inherently complex, following non-linear dynamics (Von Fellman, Bar-Yam & Minai, 2015).

Let’s now return on the example of Alexander the Great (not just the Gordian Knot episode, but his whole life) as we try only qualitatively to dig in a little bit on what “Complexity” meant in the fourth century B.C. Here we have a man (Alexander), born into a court where assassinations and intrigues were common and the capabilities required to survive were gigantic, not to forget collective phenomena as plague, famine and recurrent wars. So looking at Alexander just as a “great general” and “gifted horseman warrior” it is an evident simplification, considering that his capabilities were much more articulated just to allow him to survive in early years and become an entrusted King. Moreover, from the military side, it is not to undervalue the transformation he made out of the Macedonian “phalanxes” into an army able to travel the world and conquer gigantic empires, usually located at a distance that today could require more than two months by forced march on roads that at his time don’t even exist. This consideration leads to point out that the complexity on past time was not at all so little respect our modern world, so we should not complain on this argument as an excuse for failing in strategic plans nowadays.

Another aspect to be mentioned is the problem in taking decisions due to the necessity to satisfy a too wide community of heterogeneous stakeholders. In this contest another contestable sentence is that we have “too much democracy” and that dictatorship systems are more efficient. Indeed, the importance to have a common plan and single mind in charge is well known, as well known are it limits, as it was the case of the “Dictator”, role that Roman Republic assigned *pro tempore* to a highly qualified person, to serve as magistrate entrusted with the full authority of the Republic in order to face a military emergency or a crisis (in facing the threats posed by Hannibal of Carthage, the system didn’t prove to be so effective, however). For the reasons above, the success of strategies does not rely on just dictatorship approach. The current main problem then is related to common decision making coupled with short terms goals versus long terms achievement, and the necessity to satisfy a wide audience of supporters without the authority/possibility to lead them.

This issues are addressed very well inside CAPRICORN simulation (figure caption below), set in the Afghan province of Kapisa, in which the commander should achieve short term goals (Quick Impact Project as the excavation of water dwells) vs. long term ones (End State: pacification of the province); the Commander so has at the same time the necessity to secure the province from the insurgents and to realize water dwells and other welfare facilities. Both objectives are important; achieving one, but not the other, brings to failure.

Fig. 66 – CAPRICORN: CIMIC Interoperable Simulation

2.4.4 Strategic Engineering and Strategies

It is clear that the issues in terms of lack of strategy and poor leadership of cadre and elites, outlined above, need to be addressed by the cultural, political and military establishment of a country. On that regard, it is worth mention an emerging new discipline, defined as *Strategic Engineering*, which represent comprehensive approach to design, develop and use new solutions in order to achieve strategic results against risks, uncertainty, competitors, diminishing resources, threats and within critical environments (Bruzzone 2018; Bruzzone and Di Bella, 2019). Indeed, Strategic Engineering is based on the integrated use of innovative technologies such as M&S (Modelling and Simulation), AI & IA (Artificial Intelligence and Intelligent Agents) and Machine Learning as well as Data Science to face Challenges & Uncertainty in Complex Systems and have a wide spectrum of application fields from Defence to Homeland Security, from Government to Industrial Applications; obviously these capabilities are based on enabling technologies and advances that make possible to collect, analyse and process data in models as it was impossible in past years. Therefore, strategic engineering addresses also the crucial issue to create transdisciplinary teams where scientists and decision makers could work together, so it requires an evolution on the skill and methods in use within these categories; obviously, new Education and Training (E&T) programs will be necessary to prepare new generations to get benefit of this integrated approach.

2.4.5 *Tempus Fugit*: Time as crucial element in strategies

Among all challenges in Strategy Development, it is evident that one of most crucial element is represented by time constraints as well as the capability of achieving specific results in accordance with the planning; these elements represent probably one of most crucial element for the final success. Indeed, despite the impossibility to generalize cases, it is evident that examples are very useful to improve general understanding if the above mentioned considerations are kept in mind; so in the following, some examples are proposed.

Today, a disgruntled Public Opinion in the Western Countries is witnessing the 19th year of the US and NATO intervention in Afghanistan. In such contest, time, considered both in its physical and human perception dimensions, looks like a neglected factor in the political and military analysis in the Western Countries; this is witnessed by the current statements of US and NATO officials, which are putting the emphasis on "conditions based" end of both Resolute Support (NATO) and Enduring Sentinel (US) operations in Afghanistan. Of course not any time lapse can be pre-determined or pre-imposed, but for the same consideration it cannot be endless. Such approach however, necessary for the achievement of mission objectives (short term goal), could potentially introduce big risk of wasting a scarce resource in conflicts such as Time, marking a turn down in its comprehension and management. In any case Time, intended as physical and human phenomena, it is ineludibly and its eventual mismanagement poses serious hindrances in strategy development (long term objectives). The final line is to propose a time management in military operations vs other measurable indexes of effectiveness, by the contribution of the surging discipline of Strategic Engineering, which has the potential to achieve strategic results against risks, uncertainty in the management of Military Operations Other Than War (MOOTW), other types of Asymmetric confrontation, and Hybrid Threats.

2.4.6 Challenging scenarios

There are examples of regions, along centuries, that resulted in very challenging scenarios for military operations. Classical cases are Russia (e.g. Russian Campaigns from Napoleon to World War II) to Vietnam (e.g. Vietnam War, Sino-Vietnamese War), where it is possible to observe that the geographical region in terms of terrain and population spirit result to have a fundamental role against opponents, even when they belong to a major well trained force (Goscha 2017; Sar Desai 2018).

Afghanistan is another good example of a region able to provide many troubles to several strong players such as British Empire, former Soviet Union, United States and even NATO. Afghanistan has been going through many conflicts during history, such as Anglo Afghan Wars in the XIX century, Afghan Civil War and Soviet Unit intervention in the XX century, War against terror and Civil War in the XXI century (Jalali, 2017). Therefore, it is interesting to note that in previous centuries, when satellite and drones were not even a dream, Alexander the Great, Genghis Khan and Timur achieved success in the same region by applying each one quite different approaches; as anticipate we don’t want to over simplify, but it is evident that strategy could be successfully applied even in challenging scenarios.

2.4.7 CAPRICORN: CIMIC simulation in Afghanistan

“Throughout the ups and downs of this conflict, it's become evident that the United States is not going to defeat the Taliban insurgency, even though it can prevent a Taliban victory” (The Washington Post, 1st September 2018).

Let consider a brief exposition of the current situation in Afghanistan as for 2019 (from Press and OSINT). Nowadays, US Government feels indeed the necessity to bring to a close an 18-year-old war, even though its efforts seem to be jeopardized by the political upheaval in Kabul and the stalemate in the confrontation between Insurgents (Taliban, ISIS K etc.) and the International Community - backed Government of the Islamic Republic of Afghanistan (GIROA). The much expected negotiation between US officials and Taliban is not likely to take place any time soon, after the face turn of US administration in August 2019. Subsequent steps in order to re-open talks between US administration and the Taliban (with an embarrassed GIROA in the middle) have been taken between end of 2019 and beginning of 2020, without however any concrete outcome, so far.

This case it is a good example of how quantitative analysis based on reliable models should be applied to consider human factors and timing in strategy development. Indeed, the authors were involved, respectively as Project Leader and Military Expert, in the development of innovative M&S solutions applied to Kapisa region in Afghanistan to support operational planning for CIMIC and PSYOPS in strong connection with the general plan. The simulator CAPRICORN (Cimic And Planning Research In Complex Operational Realistic Network) was a stochastic simulator, federated with other HLA models and able to reproduce CIMIC and PSYOPS operations as well as their interactions with the human factors of the whole population in the region as well as military units, paramilitary entities and insurgents as proposed in figure below (Bruzzone et al. 2013d). The data and the scenario settings in particular belong to the province of Kapisa.

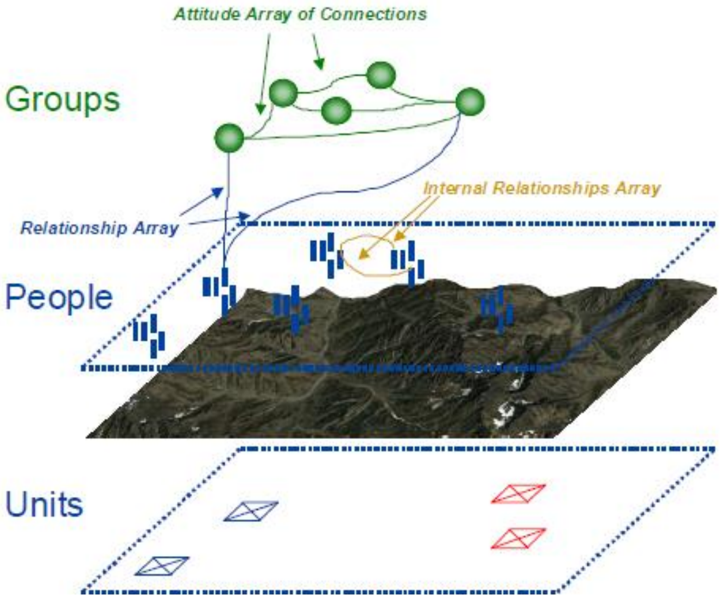


Fig. 67 - Groups, People and military Units in Capricorn

Capricorn is based on the IA –CGF paradigm, developed by Simulation Team, and it is aimed at the creation of CIMIC (Civil Military Cooperation) simulator able to consider key operational and territorial factors. CAPRICORN allows the user to set up a new mission environment, therefore enabling him to change and test hypothesis about new contests; in particular, users are entitled to define the operational planning and execute the operations in a contest of influencing the population behaviour in the affected area. Moreover, the population generated is consistent with user hypothesis and statistical data publically available; from this perspective, IA-CGF allows to define and generate, through Montecarlo techniques, ethnic, religious, political, educational and health status of each specific group of the population.

2.4.8 Time management in Hybrid Warfare and MOOTW

It was already clearly stated that according to the author, time is the major aspect in strategy development, and now we have to consider the specific concept of Time Management in Warfare (either classical/symmetric or asymmetric/hybrid form).

In the Modern era, Napoleon should be credited as the first modern Strategist that derived from the management of the forces on the battlefield an insight about the vital significance of time and its accurate calculation in relation to space. “The loss of time in war is irreparable. Space you can recover…time never”, he once asserted”. In the contemporary age, the credit to have re-introduced meaningful considerations about time and its impact in the military operations has to be given to Robert R. Leonhard, which elaborated the concepts in his opera “Fighting by minutes: Time and the Art of War”, (Leonhard, 1994).

Indeed, based on this considerations, Time could be considered as the leading factor in the Strategic Engineering analysis of Hybrid Warfare and MOOTW. This is especially true in conditions where the asymmetric threats could obtain support from local population and get reinforced while regular forces are worn down over time; obviously this situation could be capsized by getting support of the population, condition that is hard to achieve in case of time delaying operations and long term warfare, as happened in some scenarios (Galula 2002; 2006). As such condition happen, as in the case of Afghanistan, Time turns to be a decreasing resource for the so called “Western Powers”, which are affected by internal public opinion, current alliances framework and neighbouring country attitude, and last but not least, economic sustainability.

The consideration about Time drives immediate consequences about the desired End State. For instance, while a short time span corresponds to a classic military confrontation (symmetric warfare), over long time instead could evolve into a MOOTW or Civil War frame. Both of them as a certain point could potentially crash against the available Time resource; obviously this resource is not known in advance, and it is continuously decreasing. Indeed currently the authors are considering to develop a model that hazards a correlation among the time necessary to reach the End State and the most critical parameters; among these it is considered for sure the human development index of the Country to be stabilized, the GDP of the intervening country, the intervention limit threshold, identified in terms of power (e.g. task force, battlegroup, etc.) beyond which the level of commitment of the intervening nation is subject to the scrutiny of public opinion. All these elements are strong affecting the time scale and to delay specific achievements could result in losing support of public opinion, decision makers or even of your own troops.

In any case, usually the weakest among the competitors try to get more time, in order to overcome the disparity, especially if he could count on some external support (e.g. environmental conditions, local population, domestic public opinion of the opponent, financial sustainability, etc.).

In the proposed asymmetric confrontation ongoing in Central Asia, the time works against the Western Forces, while it is almost a bottomless resource for the Insurgents. From the other hand, time in Symmetric Confrontations among Global Military Powers (US, China, Russia, etc.), not mediated by any form of Hybrid Warfare, it is non-influent variable, since the power unleashed from the respective arsenals in their conventional, nuclear and cyber dimension, could rapidly (matters of days, if not of hours), determine the war exhaustion of one or both sides.

2.4.9 Strategic Engineering for Hybrid Warfare & MOOTW

As anticipated, the Strategic Engineering is the process of using engineering approaches and technologies in the designing and analysing new solutions in order to achieve Strategic Results against time constraints, risks, uncertainty, and multi faced threats in critical environments. Obviously MOOTW are very good examples of this complex scenarios, where it is necessary to develop Strategic Engineering in order to guarantee its capability to offers an effective body of knowledge (Discipline) for this purpose. Strategic Engineering as discipline should be structured in order to be able to cope with planning, execution, evaluation, assessment and lead of MOOTW and Country Building Operations, at Political and at Military Strategic levels. In a future it could be expected to have in the future a Strategic Engineering Cell, located inside a Provisional or Transitional Civil-Military Authority, with the mission to identify and build the parameters necessary for the Stabilization Requirements, developing new strategies, with an eye to the hourglass. As example, in the stabilization of Afghanistan, the Western Powers have so far followed the traditional approach, which is the one adopted at the end of WWIIs: win militarily, then initiate the dissemination of western style democracy together with an aided economic development. This was indeed right for a symmetric confrontation, where the challenge it was winning the military confrontation in its geometric domain, but has proven so far unsuccessfully in asymmetric conflicts, where instead the time, in its physical and human dimension, it is the dictating size. So far then, the security has been the primary concern to address before all the others, with a constant difficulty by the military establishment to comprehend that even overwhelming victories of the Coalition/Government Forces are turned into political gains for the Insurgents, because of the media.

In any case, the paradigm of any military operation has always been the defeat of the opposing forces. The focus has always been the defeat of the military component of the enemy, with little or to late efforts to cope with the country and the time constraints; mismanaging of those aspects lead to the disaster suffered by the French during the Peninsula Campaign (1808-1814), passing through Vietnam War and arriving to current struggle in Afghanistan. Indeed, as the long and costly US and NATO commitment to Afghanistan drags itself on rather than with a clear ending (spanning over a temporal dimension which encompass a generation), this brings further evidence that pretending to extinguish a complex conflict (which it is a jigsaw of ethnic and tribal rivalry, civil war, criminal panels, country/institution building issues, unfriendly neighbours etc.), with military means coupled with “throwing” money at the problem, - well, this has been proven to be not successful.

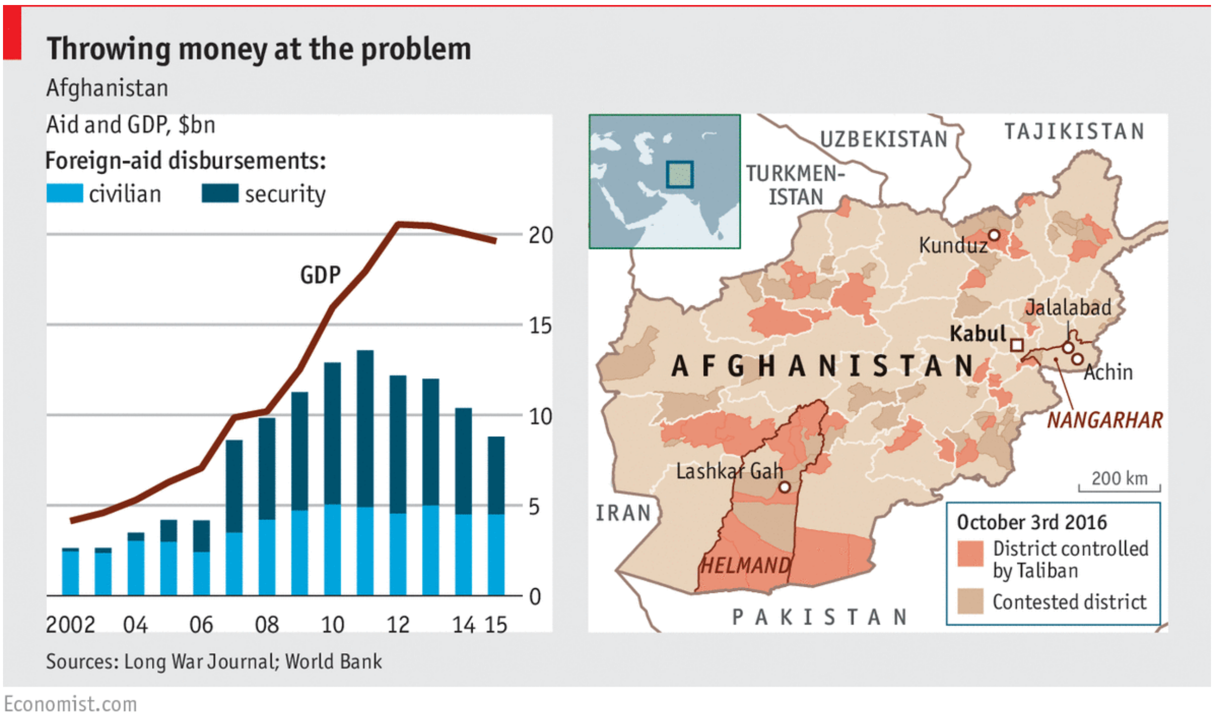


Fig. 68 – Afghanistan: throwing money at the problem (The Economist, 2015 https://www.economist.com/graphic-detail/2016/10/07/afghanistan-15-years-on).

Strategic Engineering in such contests has the potential to introduce a new dimension in the military operations, by integrating in the conflict management the capacities deriving from Quantitative Modelling for to Decision Making Support, paired with Strategic Thinking and Scenario Analysis competencies.

3. SIMCJOH: a run (time) against the clock

3.1 Project Overview

In January 2015, with the document "Gap Analysis Report on Modelling and Simulation in Support of Military Training", NATO emphasized how "Success in today's conflicts can no longer ignore the exact perception of human behaviour", and that it was therefore necessary "by creating specific behavioural models, assessing the impact of the human factor's influence in crisis or conflict situations", finally admitting that "the behaviours and motivations of both the Allies and the Insurgents are not adequately considered in the field of training, both individual and collective." From this perspective, the "Global Wargame", the annual exercise-war-game executed by US Navy, challenges the participants with complex scenarios for which there are not easily identified Courses of Actions (COAs), since the mission deal with military, political and social objectives (Levis & Elder, 2016).
It was in this context, therefore, that the "SIMCJOH" project was born.
The SIMCJOH project was devoted to carry out Research & Development (R&D) activities, with the aim of understanding to which extent interoperable simulators can be used by a Commander and his Staff to address and solve specific problems where human factors are relevant. Modelling & Simulation makes possible recreating complex scenarios and carrying out what-if analyses with the aim of evaluating the effectiveness of several alternatives (Course of Actions, COAs) and therefore prepares the Commander and his Staff to face unusual situations, in an environment which is both "Hybrid" and "Other Than War" (Bruzzone et al. 2016a). The SIMCJOH objectives are to study and develop new simulation models in order to support the decision makers in Joint and Multi- Coalitions scenarios (Peace Keeping, Low Intensity Conflict etc.), considering a strong involvement of Human Factors (either of friendly forces, opposing forces or neutral agents/population) effecting military Course of Actions (COAs) with a particular focus on issues of refugees and civilians in a theatre of military or hybrid operations (Bruzzone et al. 2015). The SIMCJOH project witnessed the involvement of military experts along the project, with an increasing understanding of potential uses of innovative M&S techniques (i.e. IA-CGF) out of traditional and established areas of application of simulators; as the IEEE Standards suggest (IEEE 2011-

DSEEP), the involvement of users from the early steps of a simulation is the best support. In developing SIMCJOH together with other SMEs, the author merged the suggestions coming from the opera of Leonhard with the categorization of time in simulation identified by Fujimoto in his book “Parallel and Distributed Simulation” (2000); in particular, Fujimoto distinguish among physical time (which refers to time in the physical system), simulation time (an abstraction used by the simulation to model physical time), and wall-clock time (refers to time during the execution of simulation). Having said that, it was of capital importance to import into the SIMCJOH conceptual model and inside the simulator later on, a *tempus fugit* perspective, meaning that the player should be feeling the pressure to deal with multiple inputs and make vital decisions in matters of simulation time minutes. SIMCJOH simulation saw then the application of the idea “to forecast the future behaviour of a system and determine what it can be done to influence its behaviour” (De la Mota, Guasch, Mota, Piera, 2017). From this perspective, Human Behaviour Modelling (HBM) and Interoperable Simulation are proving their value as an effective combination to investigate impact of operations on the population (Bruzzone et al. 2011b); it is fundamental the use of proper models representing not just people statistics, but even their complex dynamics and social interactions at different levels (Stocker et al. 2002; Bruzzone 2013b).

Fig. 69 – SIMCJOH screenshot: an angry crowd is gathering. Will the Commander be able to settle down the situation in accordance with its mandate?

From an interoperability point of view, below are reported a list of findings:

a) Easy integration through the HLA standard;

b) Testing and improvement of integration mechanisms to cooperate with other simulators;

c) Configuration and use with a hybrid HLA federation;

d) Applications working with HLA Evolved and in HLA 1516;

e) Flexible customization;

f) Proper cooperation among different types of simulators, each of them working with a different set of data and different time synchronization system;

g) Possibility to set up Hybrid HLA federation with evolved and not evolved components working together.

Reusability is another pillar of SIMCJOH, since the work done for developing SIMCJOH_VIC can be reused in other projects. In particular, the development of a UNITY3D-HLA bridge represents a valuable asset for other projects where the integration of UNITY3D based simulations and HLA is required. Similarly, the federate development phase, specifically the connection with the RTI, has been opportunely automated and this could be an additional benefit for future project activities and products.

SIMCJOH is made of 2 modules: SIMCJOH VIS and SIMCJOH VIC.

Fig. 70 – SIMCJOH VIS Starting Screen

SIMCJOH_VIS (Virtual Interoperable Simulator), represent the main core of SIMCJOH federation, and is constructed in a way that could lead to the development of a new generation of MS2G (Modelling, Interoperable Simulation and Serious Games) able to use Human Behaviour Models (HBM) interoperating with other simulators to recreate complex scenario. SIMCJOH_VIS can be used to create new dynamic scenarios for different applications, including situation awareness, education and training; as example, providing case studies where the human factors could be related with decisions and events, in order to train and improve situation awareness of hybrid environments in different geopolitical and cultural contexts. SIMCJOH system was released as a HLA federation, where future developments are open for further integration of SIMCJOH federation and/or of the SIMCJOH federates to other existing simulation assets.

SIMCJOH_VIC (Virtual Interoperable Commander) as part of the SIMCJOH federation, is the first milestone for the development of a ready to use product (namely an advanced serious game) for the education and training of those commanders that work in multi-coalition scenarios where human aspects are relevant. SIMCJOH_VIC can be further extended also to allow education and training of the commander staff and advisors, etc. (Bruzzone et al. 2014a; Bruzzone & Massei, 2017). Considering that the entire SIMCJOH system is released as an HLA federation, future developments also regard the integration of the SIMCJOH federation or the connection of the SIMCJOH federates to other existing simulation assets in the defence domain; collaborations with different agencies, research institutions and companies were the real "added value" of the SIMCJOH project, especially in the field of constructive simulator and on the ways to federate them.

Fig. 71 - SIMCJOH VIC screenshot

The SIMCJOH_VIC federate is a quite complex simulation that includes multiple models and technologies working together. SIMCJOH_VIC is developed by using C# programming language for the simulation engine and the 3D virtual environments are powered by using UNITY3D. It is worth saying that UNITY3D natively works with C#, therefore this architectural choice has supported the integration of the SIMCJOH_VIC simulation engine within the 3D virtual environments. In this phase most of the work, modelling and programming effort was devoted to implement the simulation functionalities and to develop realistic 3D geometric models (including buildings, vehicles, terrain, human models, etc.) and Virtual Environments. As far as the 3D Geometric models and virtual environments are concerned, the Virtual Environments should host and interact with three-dimensional geometric models. The implementation of the geometric models was quite a complex task. Geometric models currently used in SIMCJOH_VIC include buildings, roads, bridges, helicopters, vehicles, terrain and a number of different human models characterized by different animations. Note that textures utilization is strictly connected with the implementation into the geometric models of high-resolution and low-resolution graphic detail levels and with objects realistic representation. The SIMCJOH_VIC virtual world contains hundreds of objects that mean hundreds of geometric models and thousands of polygons. Each geometric model may have multiple textures (in order to have a realistic representation).
The interactions that take place into the Virtual Environments recreate the evolution over the time of the MEL/MIL as well as of the COAs. As mentioned before, such evolution is implemented as part of the simulation functionalities that have been developed by using the C # programming code. Consequently, the Virtual Environment provides an interface C# coded, and this was the reason to use UNITY3D as graphic engine because it provides an interface for C# programming language.

3.2 SIMCJOH VIS & VIC features and goals

The SIMCJOH Project is devoted to perform R&D activities with the aim of understanding at which extent interoperable simulators can be used, in a multi-coalition context, by the Commander and his Staff to address and solve specific problems where human factors are relevant.

Modelling & Simulation makes possible recreating complex scenarios and carrying out what-if analyses with the aim of evaluating the effectiveness of several alternatives (military term: Course of Actions, COAs) and therefore prepares the Commander and his Staff to face unusual situations (Bruzzone et al. 2014a; Bruzzone & Massei, 2017); SIMCJOH aims at developing capabilities in the area of Military Operation Planning by using CGF (Computer Generated Forces) based on Intelligent Agents (IAs), in order to support the decision makers.

Indeed, all the military commands have inside their structures doctrines in place and personnel capable to generate operational plans in a “classic” way. However, there aren’t computer programs capable to make impartial and objective evaluation; instead, these computer applications must be considered as human expert consultants that can’t act as their substitute, but just help the planners to reach better results. From this point of view, the availability of this kind of supports guarantees a methodical simplification and an improved accuracy into the military operational planning processes; in effect, the use of simulation in this context speeds up planning generation enabling the development of simpler and emendable plans in accordance with real life elements, scenario evolution and parameters changes. Therefore, in order to be effective in operational planning these simulators require to integrate advanced models capable to reproduce complex scenarios; the availability of Intelligent CFG grants the use of friendly, hostile or neutral forces, capable of features definable in terms of behaviour and "perception" of other forces, in an automatic way (Bruzzone et al. 2013d; Bruzzone et al. 2014b).

The Decision Making activities, which constitute the essential core of any command action, useless to say, allow analysis of their effectiveness only at the end of the events generated by the decisions adopted. On this particular regard however, SIMCJOH is a milestone in the direction of providing a simulation system capacity to carry out an evaluation of effectiveness of various hypothetical Courses of Action without performing those, but leaving the battlefield and digital models in its operating office to "see progress"; provide results of interactions is a challenge of high value-added and high operational content, and in fact could be a step forward in the technology of the human brain "what if", spreading up the procedures and processes, obtaining more reliable results with verifiable step by step analysis (Bruzzone & Massei 2017a). A HLA federation is able to provide external federated simulation system the ability to simulate in a more realistic and detailed way the

effects that may have some kind of activities, such as the perception of the presence on their territory by the different ethnic civilian groups. This allows the Commander/Player to choose between different options, with a reasonable degree of certainty that the simulation results are similar/does not differ to those expected from their actual implementation. The resulting simulation solutions are not expected to be predictive tools, vice versa their goal is to estimate risks and confidence bands related to different alternatives. The wide number of alternatives related to possible combination of decisions, reactions as well as stochastic driven scenario evolution makes not possible to expect to have optimisation tools able to identify the best planning or to investigate exhaustively the range of possible alternatives. In addition, operational planners are not even equipped for addressing complex experimental analysis due to their technical background as well for the time constraints for apply SIMCJOH concepts in their planning decision process. Due to these considerations, it is critical to develop metrics and key performance indexes and analysis methodologies that quickly allow to compare solutions and to understand different simulation results; this aspect it is even useful for analysts for speeding up the proper tuning of the experimental analysis.
To summarize, we may say that SIMCJHOH has been developed with two goals:
Primary goal: To provide the Commander with the capability to investigate the consequences of different decisions in terms of collateral damages, PMESII second effects;
Secondary Goal: overcome interoperability issues, and demonstrate technological capability to combine Strategic Decision Making Models with other simulation models for further developments in terms of CAX, Educational Programs and/or future Operational Planning and On-Line Decision Making. Computer Assisted eXercise (CAX), with several federated simulation joint and single service simulation system, with different complex level and aggregation, can help the target audience to achieve good training results in the simulation of military operations in digital battlefields (Cayirci and Marincic, 2009; Mastrorosa et al. 2012). In a CAX contest, SIMCJOH fits very well, because it has a basic capability in the complex and critical sector of military operation planning, using Intelligent Computer Generated Forces (CGF) made by intelligent software agents, which feasibility and initial development was reached with previous Simulation team projects outcomes (Bruzzone et al. 2011b, 2013d, 2014a, 2015b).

3.2.1 MEL/MIL Flow Charts

With regard to SIMCJOH primary goal, the implemented software focuses on two specific Main Events List/Main Incidents List (MEL/MIL):

1. Village Block: fully operative and subject of the final SIMCJOH demonstration;
2. Special Force Raid: entirely structured, to be implemented in future projects.

SIMCJOH_VIC is a dedicated framework in which the commander observes the evolution over the time of specific scenarios (MEL/MIL) and Course of Actions (COAs). The current virtual environment includes two small towns, one village and one refugees camp in which the different MEL/MIL and COAs could be applied.
This framework was finalized based on MEL/MIL and COAs defined within the SIMCJOH project framework, but could be further extended.
All the COAs contained in each MEL/MIL are characterized by multiple stochastic variables that, within acceptable ranges, can be randomly generated in order to create tens of MEL/MIL and related COAs, providing the Commander with a new experience every time the SIMCJOH game is used.
The following six figures below depict, based on flow charts, the conceptual models of the MEL/MIL COAs; the use of flow chart allows pointing out all the logical relationships among the different decision elements each COA entails. Moreover, within each flow chart it is possible to observe:

- the difference between the Synchronous Activities and the Asynchronous Activities;
- the possibilities for the Commander to ask for additional information, data or evaluations in different point of the COA and to take decision according to the feedback provided by the Staff.

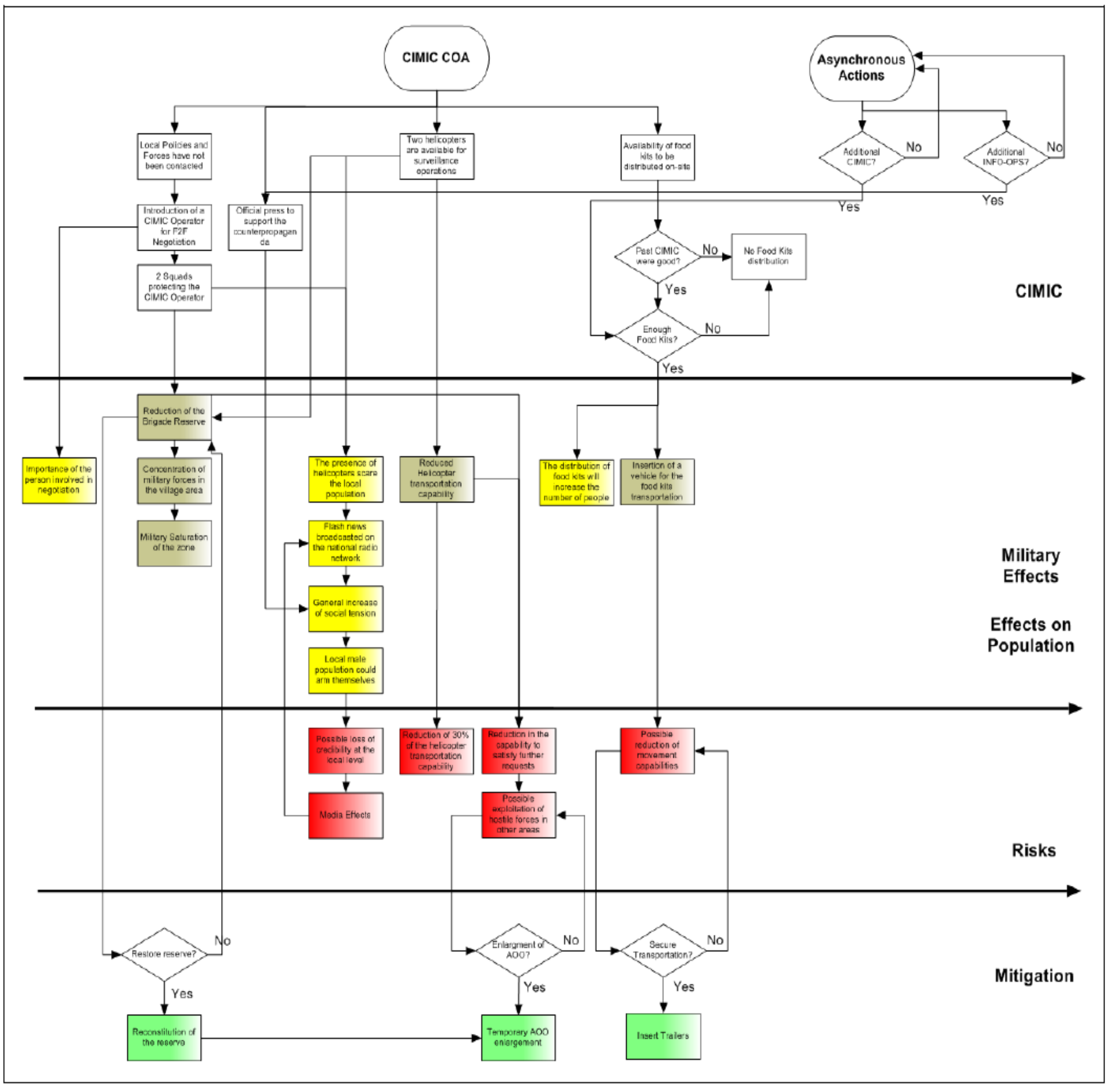


Fig. 72 – Flow-Chart Conceptual Model of the MEL/MIL 1, COA 1

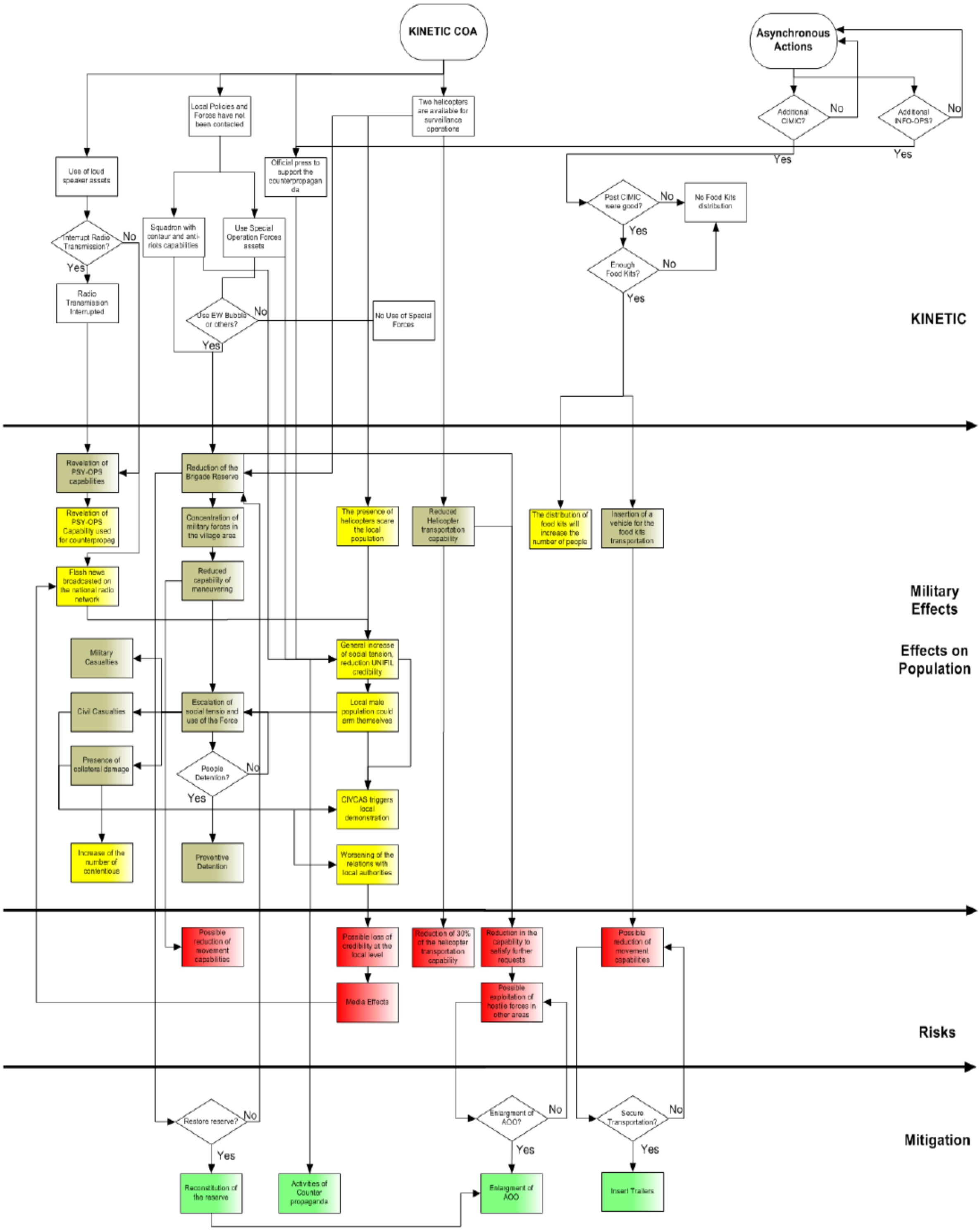


Fig. 73 – Flow-Chart Conceptual Model of the MEL/MIL 1, COA 2

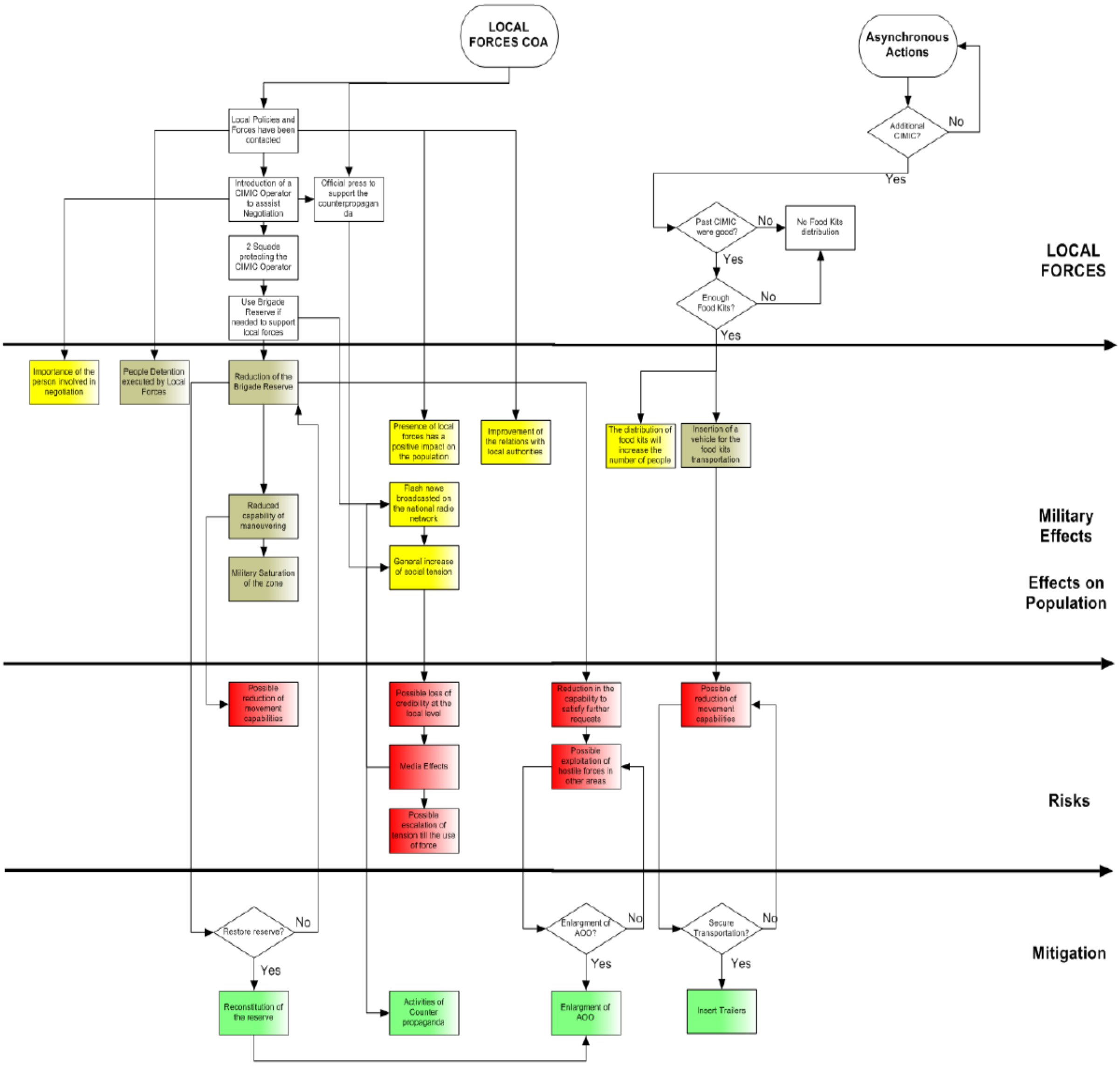


Fig. 74 – Flow-Chart Conceptual Model of the MEL/MIL 1, COA 3

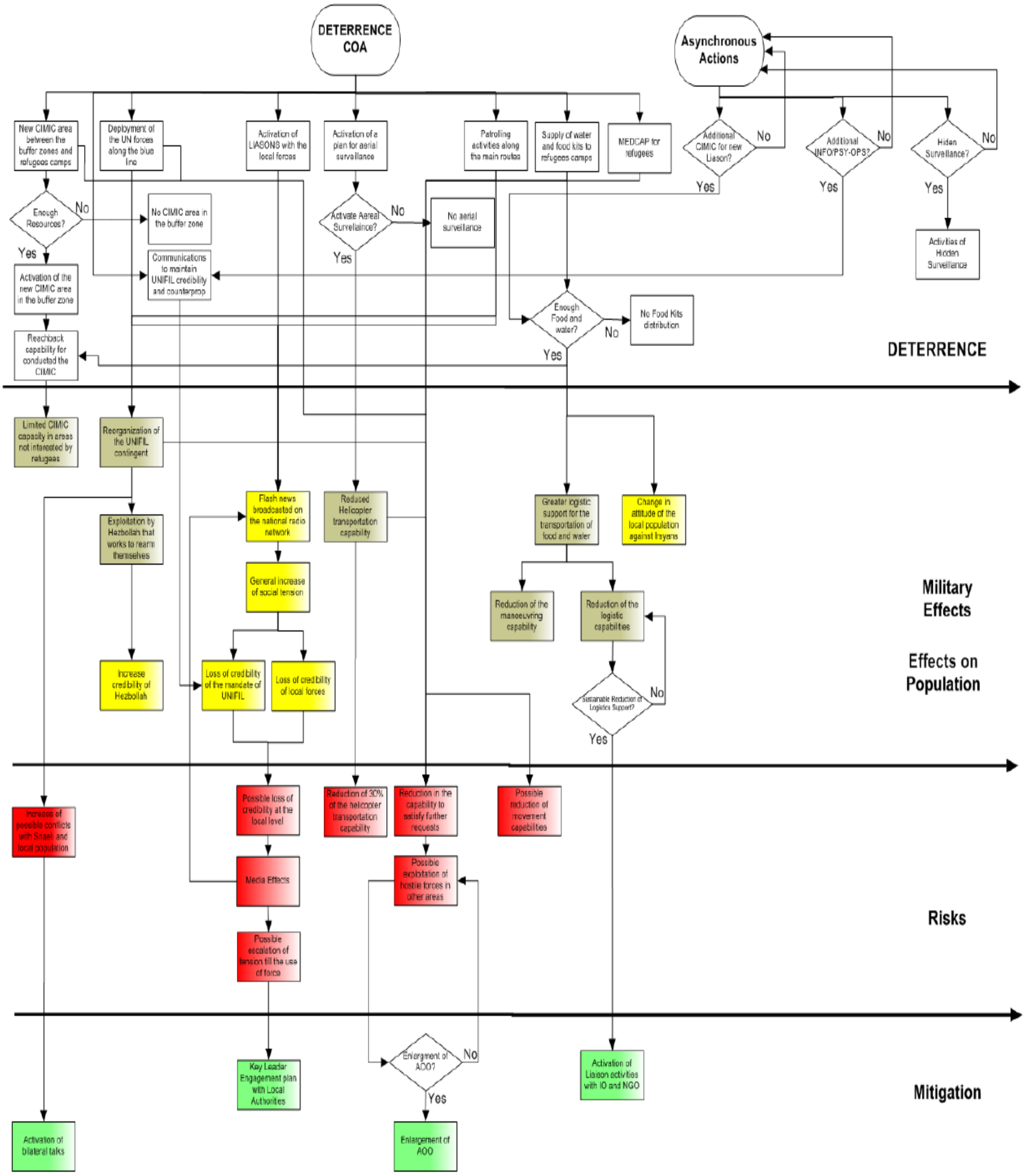


Fig. 75 – Flow-Chart Conceptual Model of the MEL/MIL 2, COA 1

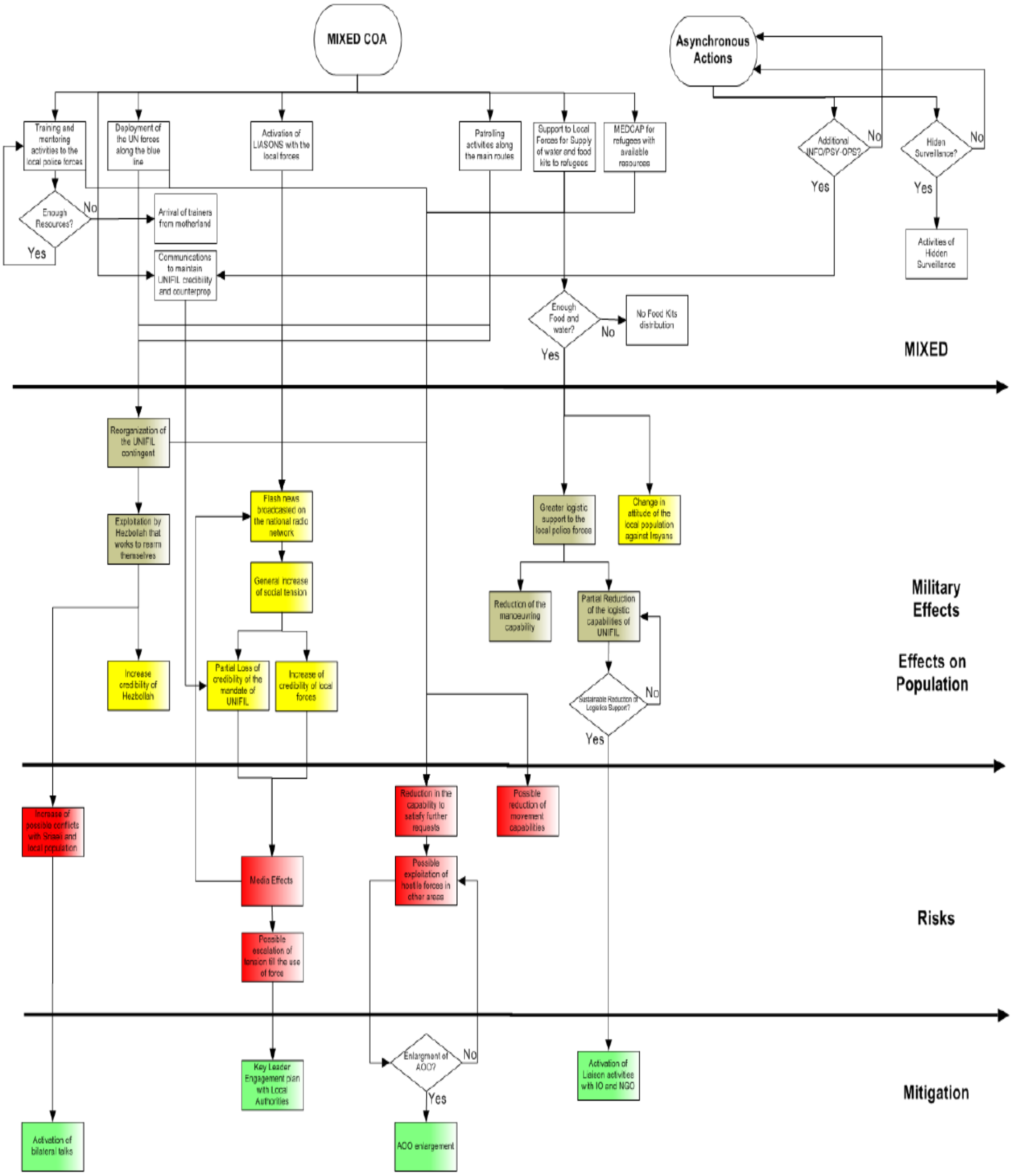


Fig. 76 – Flow-Chart Conceptual Model of the MEL/MIL 2, COA 2

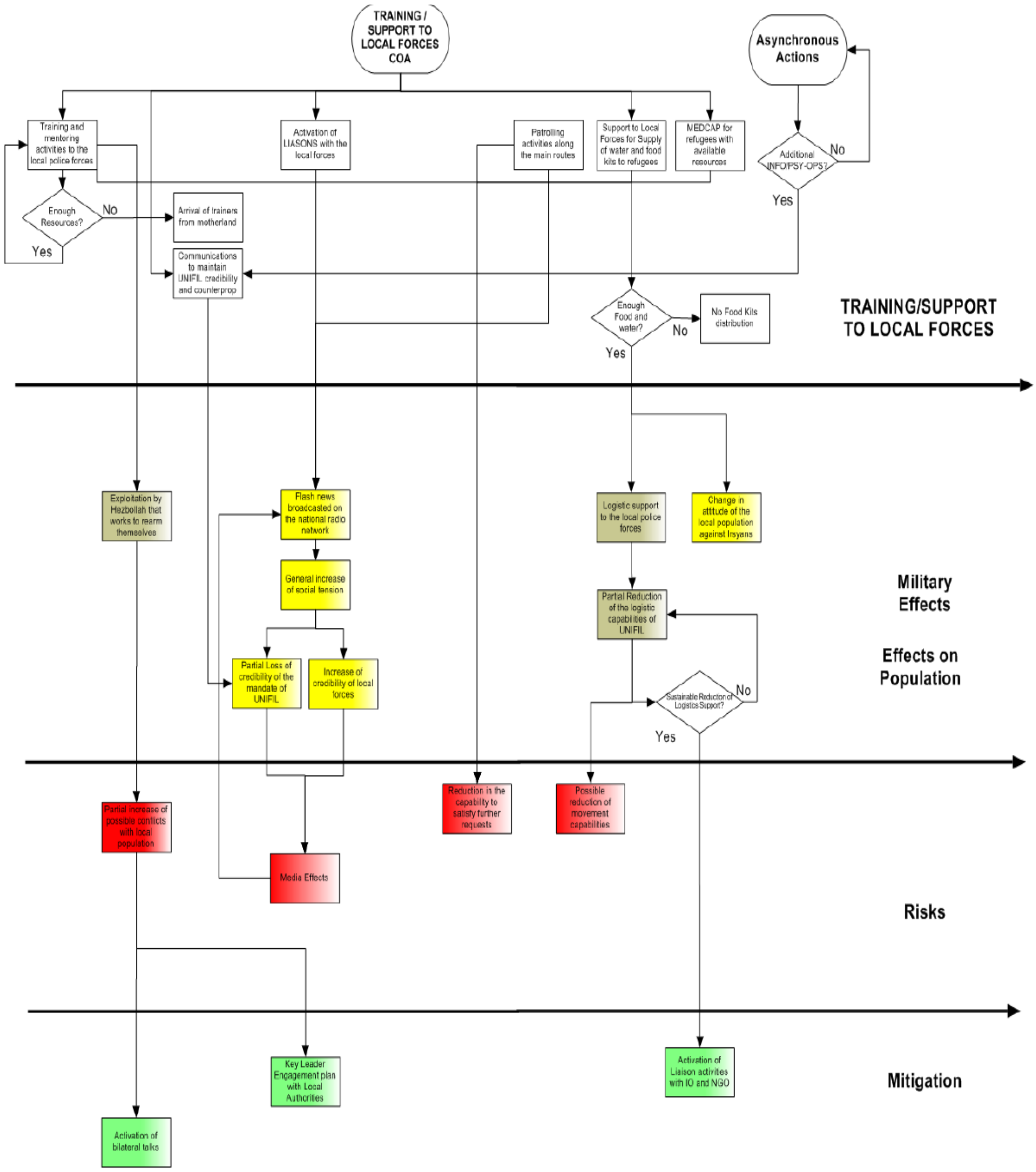


Fig. 77 – Flow-Chart Conceptual Model of the MEL/MIL 2, COA 3

All the COAs contained in each MEL/MIL are characterized by multiple stochastic variables that, within acceptable ranges, can be randomly generated in order to create tens of MEL/MIL and related COAs, providing the Commander with a new experience every time the SIMCJOH demonstrator it is used.

3.2.2 HLA Classes, Objects and Interactions.

In compliance to HLA standard, SIMCJOH Federation includes definition of Federation Object Model (FOM, for the entire federation) and Simulation Object Models (SOM, one for each single federated). The FOM specifies all the information the federates will exchange each other during the simulation and therefore includes the object classes, the attributes, the interactions, the parameters and any other information relevant to the federation. On the other hand, the SOM specifies all the information that each single federate may provide to the federation and all the information that each single federate may receive from other federates through the Run Time Infrastructure.
Within the SIMCJOH federation, exchanged data are grouped in terms of attributes when the data are persistent, in terms of parameters when data persistence is not required. Each class corresponds to an entity belonging to the real system (scenario) and classes and interactions are organized in a hierarchical structure where each sub-class inherits properties from another class.
Objects: one Object class that represents each vehicle or system present in a defined scenario.

Table 4 – SIMCJOH Object Class Structure

Class	Definition
Asset	Every asset on which sensors or weapons are mounted in the scenario e.g. aircraft, drone, ground unit, demonstration…

Interaction: An interaction is an explicit action taken by a federate that may have some effect or impact on another federate within a federation execution. Interaction is a messages related to MEL/MIL happening within the scenario; this Interaction Class is defined Player-Message and it has been introduced in order to allow SIMCJOH Federation to exchange messages about Commander decision.

Table 5 – SIMCJOH interaction class definition table

Interaction	Definition
Player_Message	Message exchanged among SIMCJOH Federates

In order to categorize SIMCJOH, it is necessary to point out that there are three different types of simulation identified in Modelling and Simulation world:

- Live Simulations. A Live Simulation is a simulation involving real people operating real systems, with simulated effects.
- Virtual Simulations. A Virtual Simulation is a simulation involving real people operating simulated system. Virtual simulation injects human-in-the-loop in a central role by exercising motor control skills (e.g. flying an airplane), decision skills (e.g. committing fire control resources to action), or communication skills (e.g. as members of a C4I team).
- Constructive Simulations. A Constructive Simulation is a simulation that involves simulated people operating simulated systems. Real people stimulate (make inputs) to such simulations, but are not involved in determining the outcomes.

SIMCJOH federation includes virtual and constructive simulations; no requirements are present for live simulation, despite the fact that by adopting HLA it is possible to include in the future real-equipment and real war-fighters in the SIMCJOH Federation. About the virtual aspects, the human operator is involved in the control of the Decision Maker in SIMCJOH Federate as well as in other constructive simulator, exercising his decision skills giving commands to the Coalition Units, while the other SIMCJOH actors are driven by IA-CGF. About the constructive aspects, the human operator is able to modify some IA-CGF parameters at the starting of the simulation in order to change the scenario evolution (i.e. difficulty level).

Fig. 78 – Simulation initial set-up

3.2.3 Lessons Learned

SIMCJOH project demonstrate the importance and the necessity of a proper cooperation among modelling development team, simulation experts, and Subject Matters Experts. Nevertheless, collect the right mix of skills is pretty complex, and it is evident that different competencies are required to have the right balance to produce useful and reasonable results in terms of requirements: modellers, expert of military simulation, military personnel with an operational background, people with experience of the reference scenario, simulation scientists and specialists. This mix usually is difficult to be created, in particular in the early phases of a project; in addition, these resources are pretty hard to be coordinated due to the fact that often are pretty overloaded and sometime even located in different places, with limited capability to move and/or work in distributed teams. SIMCJOH, however, in accordance with the suggestion of IEEE 1730-2010 Standard, witnessed the involvement, since its early steps, of an enthusiastic Community made of Military Experts and Simulation scientists: the former able to address the project towards its broad goals, the latter keen to implement in the demonstrator the mechanics descripted by the former.

Additionally, this project has provided an important contribution to disseminate the potential of using use M&S to face complex Military and Homeland Security issues. The involvement of military experts evolved along the project and created a virtuous loop, where users disseminate these results in the military community becoming good promoters of the project and allowing to find and involve new experts from different offices. The above described lessons learned recall perfectly the difficulty in the collection of reliable data and information about scenarios; in real operations, rather than in a R&D activity like this one, the preparation and the validation of the mission environment will be a critical issue.

SIMCJOH architecture proved to be flexible, able to be federated with other simulation systems through HLA; in the Defence area, adhere to standards gives value to the simulation models. Thus, having SIMCJOH_VIC as HLA-compliant fosters model interoperability and reusability. In HLA mode, it is demonstrated the capability to federate the different Models providing a complete and flexible approach. The integration tests carried out has revealed, above all, the possibilities to develop additional functionalities (e.g. the possibility to control the SIMCJOH_VIC real time simulation from the SIMCJOH_VIS discrete event simulation), opening the way to new solutions and to the integration of different technologies and methodologies.

SIMCJOH Project addresses the problem of providing support in evaluating complex situations dealing with human factors in order to complete scenario analysis or decision making; the context of application is related to operational planning, with special attention to stabilization and normalization process (Bruzzone, 2013d). SIMCJOH aim is to demonstrate the potential of the M&S use as a virtual framework to investigate alternative hypotheses on the scenario and different decision impacts on PMESII conditions. In fact, these aspects need to be addressed because there aren’t simulators covering those aspects integrated with operational planning, and therefore is a need by the users and analysts to access models to test and evaluate alternatives. Based on subject matter expert feedback, it emerged that it is not possible to consider operational planning separating specific aspects from other ones (i.e. considering just operation planning without considering logistics, military support, etc), as well as the fact that the scenario complexity is explosive for several aspects (i.e. time constraints, background knowledge available, etc.).

Summarizing, we can say:

- SIMCJOH Models get benefits from being able to be federated with other simulation tools (i.e. GESI);
- it is often easy to replicate military operation, but it is very difficult usually to simulate human behaviour of the involved civilians;
- it is impossible to manage operations without integration with other operative elements (i.e. C2, Intelligence, Operations, Logistics, etc.);
- it is still mostly impossible to represent all the actors operating on the battlefield, that’s why cooperation among different Simulation Tools provide strong benefits;
- it is fundamental to construct scenarios consistent and well defined in terms of boundaries and ranges of application, in order to guarantee the possibility to obtain useful results;
- the knowledge is as important as the technology (social knowledge versus sensor data collection);
- it is mostly impossible to reproduce a mutant force both in qualitative and quantitative terms;
- the number of variables to be used in PMESII dimension are very high;
- the focus it is on the stabilization phase;
- it is critical to consider asymmetric threats;
- in terms of system tools features, the most important aspects are related to decision making support and training.

The analysis of SIMCJOH results highlight the benefit of using Intelligent Agents; indeed, the project get benefits of reusing IA-CGF developed by Simulation Team for different application (es. CAPRICORN).
As far as the SIMCJOH_VIC development is concerned, the major strongholds are namely the UNITY3D-HLA bridge and the work done to automate the federate development process.
Finally, the SIMCJOH Demonstration was carried out on MS COE by presenting all the different models, as well as the whole SIMCJOH Federation; thanks to the flexibility of the proposed architecture, SIMCJOH could operate also in stand-alone mode as well as on a local network of laptops. The Stand Alone Mode allows Commanders to evaluate impact of different COAs and possible evolution of the

scenario. Demonstration consisted in presenting the evolution of MEL/MIL1 respect a Village Block in the country of “Eblanon”, set in a realistic Middle East Scenario. The users get their situational awareness through the combination of dynamically generated reports from Virtual Assistants, tactical situation and virtual representations.

SIMCJOH has been very successful in its unique capability of demonstrate to the player the importance of the time dimension and the corollary concept of phases. Even after several thousand run of the game, the player can experience a challenge where despite his/her best efforts and timely coordinate actions, the failure or the success often lies within a single factor not properly addressed; the player it is not merely challenged to react, but as well to deploy all the possible means and to use the avatar staff to identify the COAs and then to make his/her choice. Of course, the way out from the village (which represents the only set of victory conditions) bounces between the complete surrender of the military unit (not acceptable), and a fire engagement to clear the surrounding hostiles – together with the inevitable loss of civilians (not acceptable as well). Somewhere in the middle (?), and with several level of accomplishment, lies the solution.

Fig.79 – SIMCJOH caption: no easy way out: armed civilians spotted!

3.3 Population data model, technical pre-requisites and demonstration test

The population model could operate both in federated mode with SMICJOH_VIC and other Simulators (e.g. GESI), as well as in stand-alone mode by using meta-models of other missing federates.
SIMCJOH_VIS reproduces the evolution of the population characteristics (i.e. fear, fatigue, aggressiveness, stress, demonstration size) as well of the other boundary conditions (i.e. deterrence, entities and unites, NGO); SIMCJOH VIC allows to present the dynamic situation and to manage the behaviour of individual virtual entities. Population model simulates the Eblanon population; in the scenario the population reacts dynamically to events and actions carried out by the different parties present in the area.

3.3.1 Population data model

For the purpose of demonstration, three different villages could be activated for the crisis; their configuration is variable even if the geographical location is correct. The locations used are in South Lebanon and corresponds to Btaichiye, Aalma ech Chaab, Chamaa. Each village is characterized by a possible variable combination of the population attributes; for instance, in relation to MEL/MIL 1, the population reproduce the inhabitants of the village where the block takes place. Among the population attributes are listed:

- Religion
- Political Party
- Ethnic Group
- Stress
- Fatigue
- Aggressiveness
- Fear
- Sensibility to Deterrence
- Hostility versus Coalition
- Security Needs of the Population
- Size of the Demonstration blocking our Squad and trend
- Consensus on Italian Armed Forces

- Coalition Trustiness on Local Media
- Coalition Trustiness on Domestic and International Media
- Perception of the Last CIMIC on Site and Time Elapsed since its completion
- Economic Status of the Population
- Impact of Insurgents on the Population
- History of Coalition Attacks on Site in terms of Frequency and Intensity
- Influence of Local Police
- Influence of Media Coverage
- Influence of Social Networks
- Current Disposition to Negotiate
- Negotiation Capabilities (from both sides)

Religion, Political Party and Ethnic Group are generated based on statistics of the area and correspond to major different groups - Alawites, Shia, Sunni - with a different presence of irregular forces such as Hezbollah, generic terrorists or ISIS, in the designated village. The attributes describe population status in term of psychophysical and social condition value are influenced by the events and decisions taken by Commander as well as by the operations; previous history of activities on the village affect future evolution and should be taken into consideration to drive the Commander decision in dealing with the population.

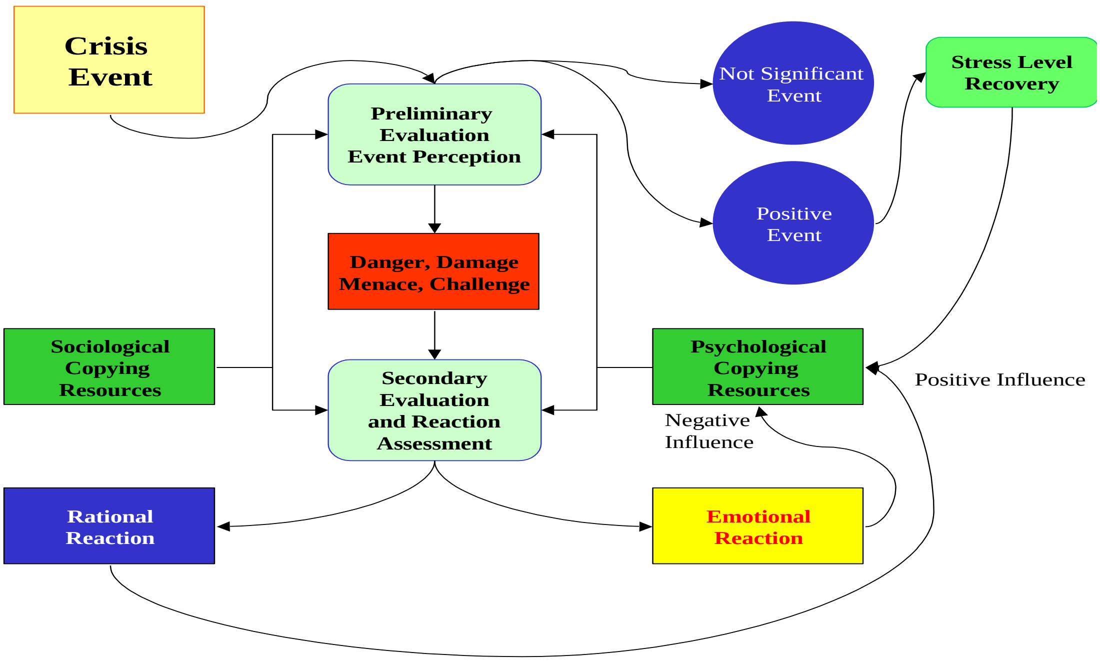


Fig. 80 – A dynamic generation mechanism of fear

For instance, the result of last CIMIC operations in the village itself affects the negotiation capability of the responsible as well as population attitude; as example, the Commander can gain such information by questioning his staff – the J2 avatar – and receive a report in the form of a military-formatted briefing.

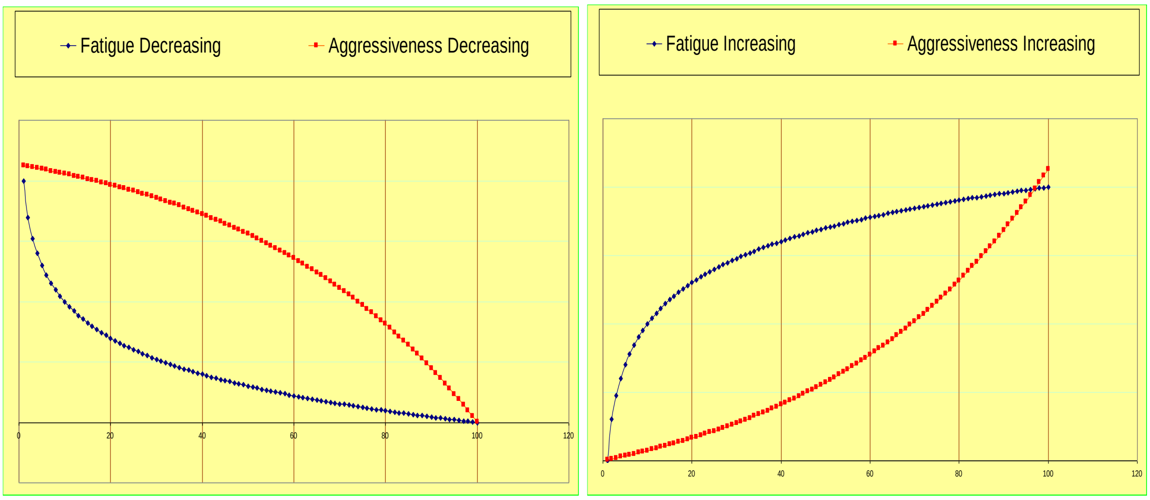


Fig. 81- Fatigue is characterized by saturation in increasing and faster recovery during early phases in our range of analysis; Aggressiveness increases based on exponential escalation and relaxes back slowly (i.e. "it is easy to tease but hard to get released")

Events are generated by stochastic statistical and determine also spot situations that could lead to crisis (e.g. accidental WIA during the block), as well as the needs of care for inhabitants. These values are dynamically updated during the simulation and determine the reaction of the population when a Commander undertake decisions leading to new actions. For example, the use of a helicopter affects population as a deterrent, but could accumulate tension, at some point this could grow up to critical level, with risk of riot and escalation.

The number, status and composition of rioters blocking the military patrol change dynamically with the variation of the level of social tension: if this value increases, the number of villagers increases direct proportionally. The risk of a riot rises when social tension level is high, and computer generated riots are simulated with a given probability (i.e. rioter car burning, stone-throwing against the blocked squad, individuals with firearms among population pop-up, and in extreme dangerous situation some snipers can start to lurk on a nearby minaret).

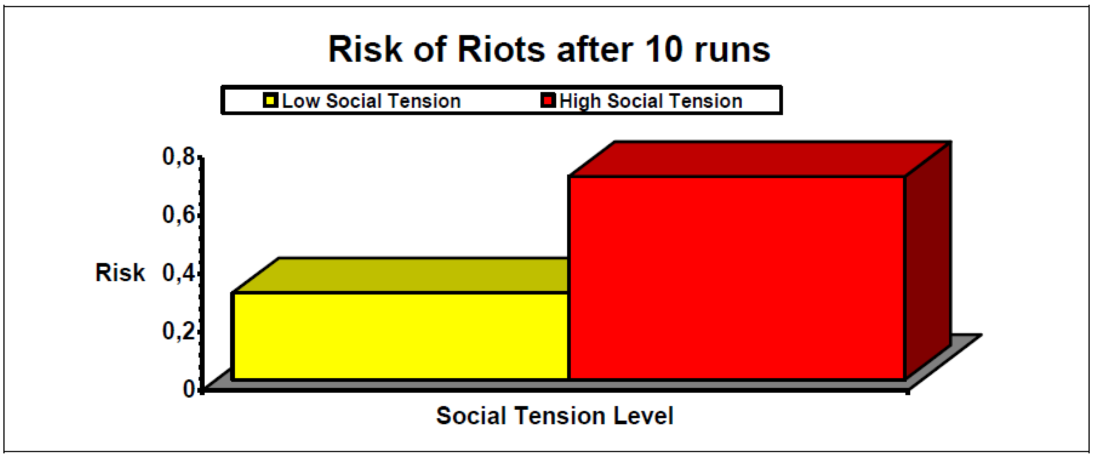


Fig. 82 Risk of riots related to social tension level

The test plan is based on the demonstration of the effect of the different actions and boundary conditions on the Population behaviour as well as their impact on the block; indeed, the simulator could consider also kinetic actions as well as rioters attacking military units.

Fig. 83- Dynamic situation update

The situation of the population is dynamically updated inside the simulator SIMCJOH VIS and reports are provided to the Commander both graphically, textually and as Staff Reports; a dynamic evolving Virtual Simulator could be federated in HLA providing to the Commander the possibility to view the Village situation as well as operations by God Eye or as Streaming for Field Sensors.

3.3.2 SIMCJOH: technical pre-requisites

Population Constructive and Logic model is embedded in SIMCJOH VIS and works both in Windows and Linux Environment, in HLA mode and in Stand Alone Mode. Population Virtual World is embedded in SIMCJOH VIC and runs on Windows and provides direct control to the scenario, in case it is required to use it for stand-alone demonstrations; both systems are interoperable by using HLA Standard. The two simulators models (VIS & VIC) have been tested in Windows environment; since it is developed in Java it is platform independent (Windows, Linux, Mac) but require JAVA Virtual Machine.

In order to operate them in connection it is required to install HLA RTI; currently the system operates on MÄK, so it is necessary to install MÄK RTI version 4.2.

SIMCJOH VIS and VIC could operate in separate workstations or on the same computer, sharing the screen, mouse and keyboard.

Hardware required: Hard Disk 500 Gb, RAM 8 Gb, OS Windows. Tests has been conducted on LAN, WAN through VPN and Single Workstation using Windows OS.

Model Basic Installation Procedure:

- Copy the SIMCJOH folder and all subdirectory on the Computer
- Create a link on your desktop

Install the Java Virtual Machine (e.g. Java 8)

For HLA Mode Install the MÄK RTI

Model Basic Execution Handbook:

- double click on SIMCJOH_VIS JAR Executable to run the simulator stand alone
- or double click on SIMCJOH VIS run Mak Bath to run in HLA.
- Select the Game Mode “Village Block”

The buttons have tips to provide suggestions.

For stand-alone mode just click the Run / Play button and select decisions by clicking on Virtual Assistants; double click on different decisions provides automatic reports from the staff and allow to ask additional information.

Configuration allows to change from Stand Alone (default, by click on "simulation model" and tick the box "stand alone") to operate HLA Mode (by click and selection of RTI to be used, the current demonstrator use just MAK); to Close the program click "quit" button.

Fig. 84 – Activation of MEL/MIL 1 (village block)

3.3.3 Demonstration Test

The test was conducted on SIMCJOH VIS in stand-alone, with the behaviour of population during the Village Block on MEL/MIL1, considering the stand-by condition as well as the application of COA Kinetics. Initial Conditions and boundary conditions are default for MEL/MIL1; no change are required on the input parameters or in configuration respect SIMCJOH VIS default configuration.
The user activates the scenario clicking on Simulation; then activate the run by clicking "run button", and the simulator generates a block in a village as proposed in SIMCJOH VIS Interface. The Virtual Assistants (operating as Commander Staff), controlled by the computer, generate automatically the report about the situation, considering time required to collect info about the situation (minutes to hours). This was a precise requirement addressed to the SMEs to the SIMCJOH developers, in order to tackle with the real-life process of collecting/evaluating information and present them in a proper way to the Commander.

Fig. 85 – Virtual Assistants, recalling the main functions inside a military staff

The report on the situation is generated to support commander decision and provides an overview of Village and Population based on current perception; this perception modifies during the run based on additional info (i.e. Recce or Intelligence) as well as scenario evolution. The report is presented in the figures below, and it is represented in a format similar to those employed in UN peace operations.

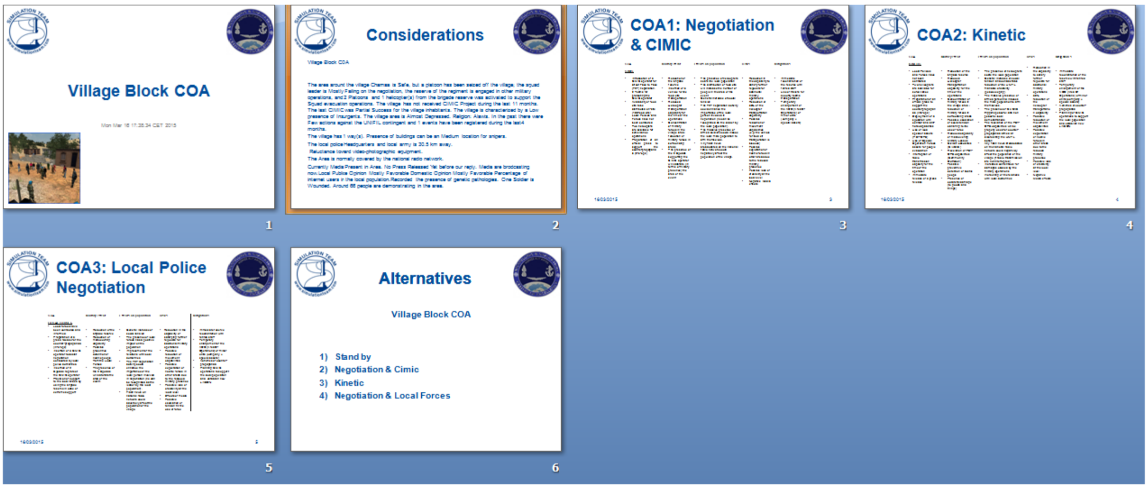


Fig. 86 – Crisis reports generated automatically and updated dynamically by SIMCJOH VIS

Indeed, the report is generated dynamically by the simulator based on current situation of the scenario considering the time and workload required by the staff to report the commander, in similar way the decision taken require to be activated.

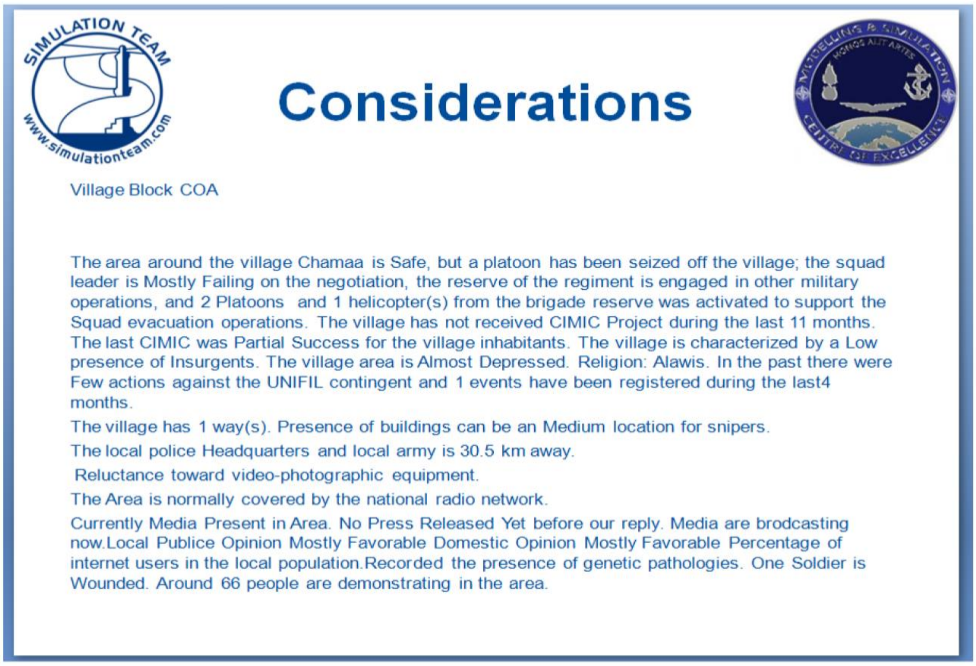


Fig. 87 – Summary report about the ongoing crisis

At the beginning of the situation, the Commander/player chose the option of hold on, while the demonstration and tension into the village grow as proposed in the collected images below.

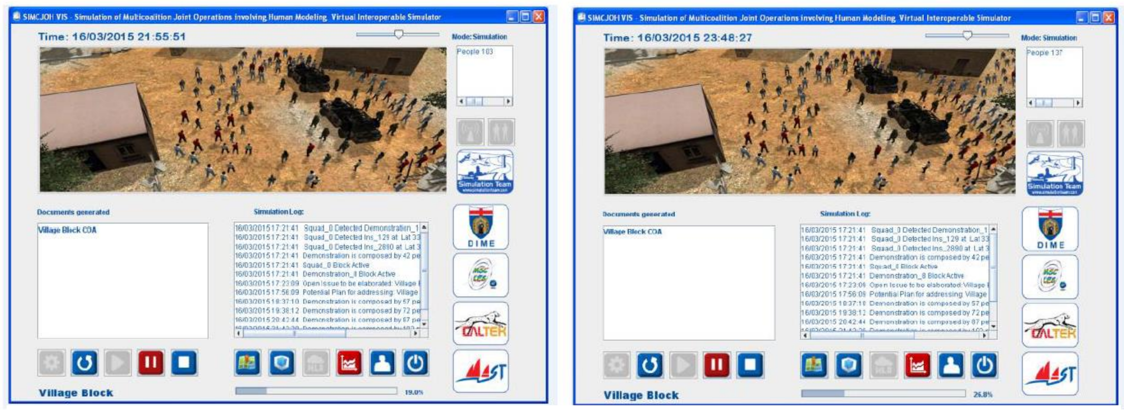


Fig 88 – Screen caption of a game in standby (pause)

Within the required time, the COA is activated and all the options to made changes are available for the Commander; during this test no any change from default plan proposed by the Virtual Assistant is activated; following figure present already an improvement in reduction of the demonstrators (from over 130 to under 100) due to the applied deterrence.

At this point the Commander issue the order to the Virtual Assistants to activate, among those proposed, the COA “Kinetic” (here kinetic is to be intended as an engagement, but below the use of lethal force. It can employ different assets and means, and almost rely on the deterrence displayed by a show of force, carried out by a resolute army).

Fig. 89 – Decision to activate a kinetic COA

In this case, the adoption of a Kinetic COA had the effect of pushing the people out of the demonstration site, as reported in figure below:

Fig. 90 – Effect of COA activation

Indeed, the Block is removed by use of deterrence and the squad is free and moves out, completing the simulation with success. Detailed reports are available in the graph as proposed in following figures:

Fig. 91 – Demonstration shuts down due to the success of the chosen COA

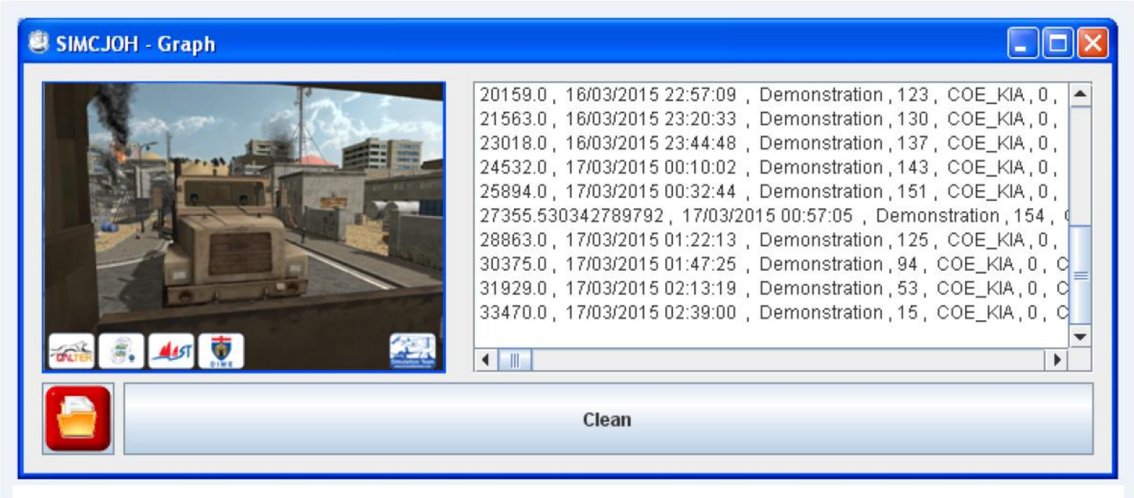


Fig 92: Target function report with figures scroll of the scenario

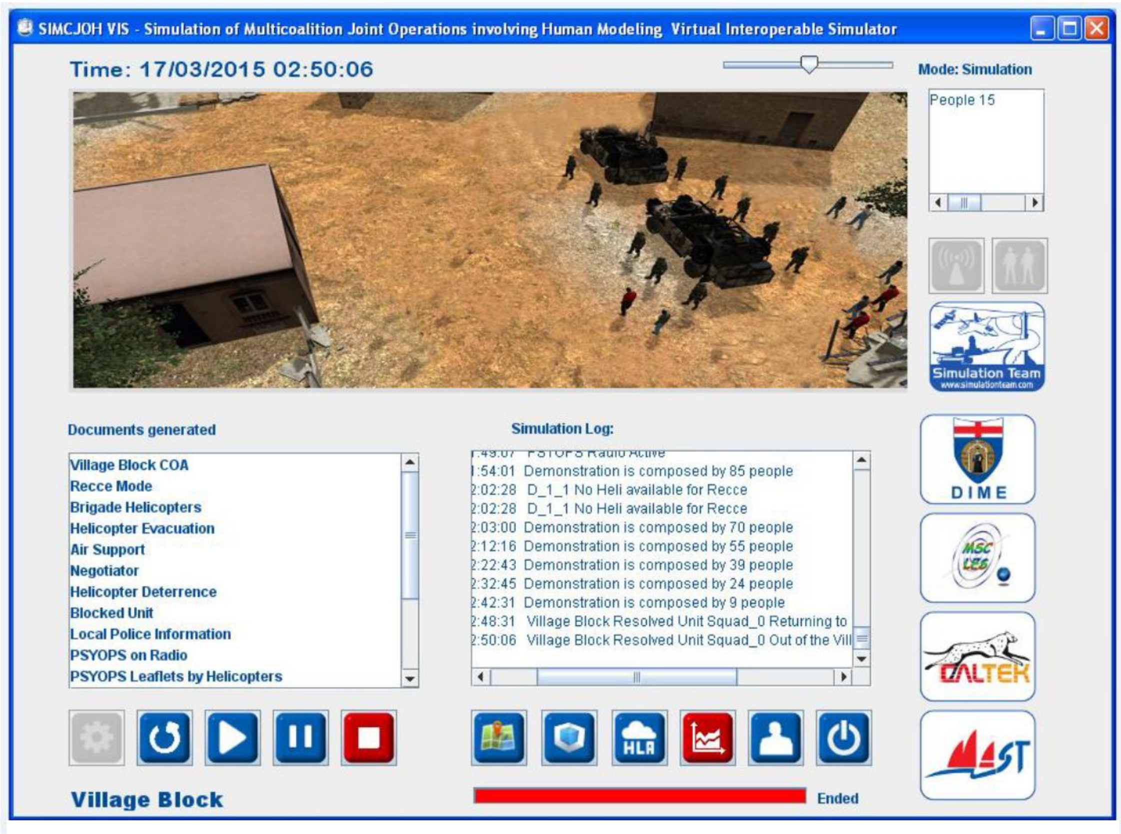


Fig. 93 - End of simulation: last line of the log announces that the military unit is out of the village.

It is important to outline that due to the stochastic nature of the simulator, repeating the run results could generate differences respect a measurable confidence band, as analysed in the experimental analysis report of SIMCJOH.

3.4 VIS &VIC working configurations and experimental test sets

Multi Coalition Simulation Model is implemented in SIMCJOH_VIS simulator. It can run both federated with SMICJOH_VIC simulator and stand alone with a meta-model; SIMCJOH_VIS provides the different condition that are visualized in SIMCJOH_VIC simulator. Next are reported all the tests that have been executed by using the SIMCJOH_VIC simulator

3.4.1 Working configurations

The SIMCJOH_VIC (Virtual Interoperable Commander) is one of the simulator that are part of the SIMCJOH federation; it can run both stand-alone and connected as part of the SIMCJOH federation, based on the standard for distributed simulation HLA 1516-2010 Evolved. However, it should be noted that within the SIMCJOH framework, the commander is allowed to take decision through the SIMCJOH_VIS simulator (Virtual Interoperable Simulator) and therefore observe the effects of his decision within SIMCJOH_VIC. As part of this architecture, SIMCJOH_VIC also includes specific analytical models that are used to recreate realistic scenarios. To cite a few, the following models are included as part of SIMCJOH_VIC: Multi-Coalition model, the real-time Helicopter motion model over 6 degree of freedom, the real-time military vehicles motion model. In addition, the SIMCJOH_VIC also includes a number of dedicated animation that are used to recreate realistic human models both for the civilians and for the military. As already mentioned, SIMCJOH_VIC is also able to run stand-alone; to this end, it has been implemented to allow future developments and to run even outside the SIMCJOH reference scenarios, since it has been developed as HLA 1516-2010 Evolved, in order to allow future connection with other federate/federations.

The execution of the SIMCJOH_VIC simulator as part of the SIMCJOH Federation requires in addition the license of the MÄK-RTI Version 4.2.

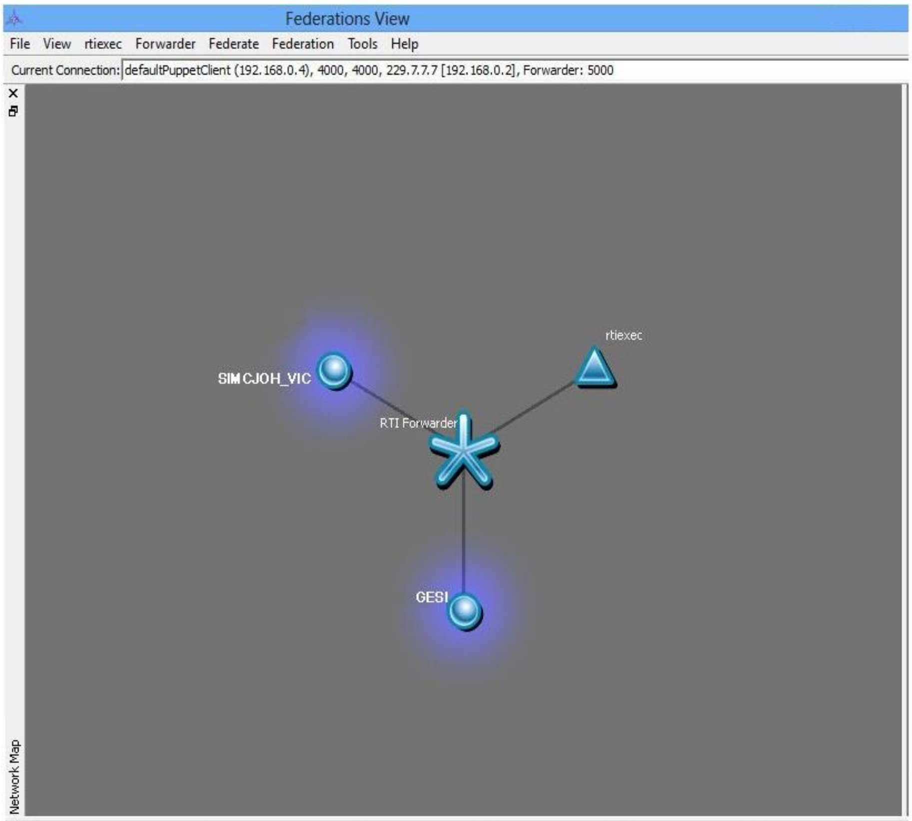


Fig.94 - SIMCJOH Federation including SIMCJOH_VIC and GESI

Launching SIMCJOH_VIC simulator executable in stand-alone mode requires a commercial desktop PC running with Windows Operating System.

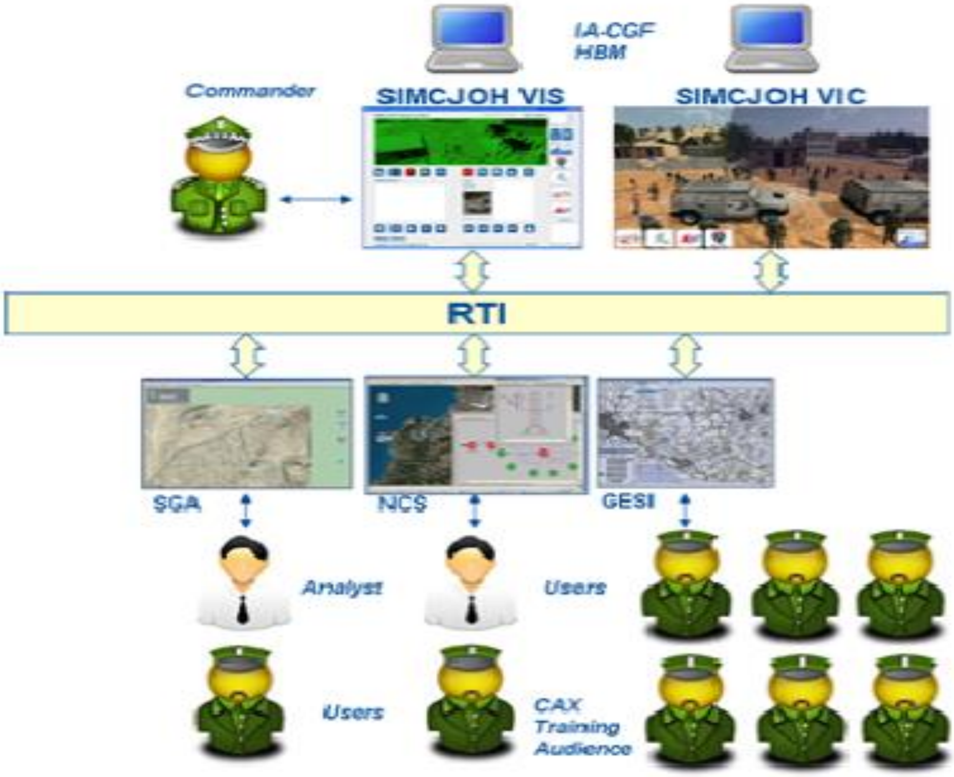


Fig. 95 - SIMCJOH Federation including SIMCJOH_VIC and GESI

SIMCJOH_VIC HLA Execution: to run SIMCJOH_VIC as federate of the SIMCJOH HLA federation, the procedure is the following: - run the MAK RTI version 4.2 - run the SIMCJOH_VIC executable that will connect automatically to the SIMCJOH federation - run the SIMCJOH_VIS executables to connect the SIMCJOH_VIS to the SIMCJOH federation. In this case, the SIMCJOH_VIC functionalities are controlled directly by the SIMCJOH_VIS federate, therefore the user interface is disable in SIMCJOH_VIC. You could run each SIMCJOH federate on a different machine connected over a LAN (e.g. the SIMCJOH_VIC running on machine 1 and the SIMCJOH_VIS running on machine 2). Be sure to install and run correctly on all machines the MAK RTI version 4.2 before running the SIMCJOH Federation. Please note that the SIMCJOH_VIC will work properly only if the SIMCJOH_VIS is connected to the federation and running (as mentioned in the HLA mode the SIMCJOH_VIC is controlled by the SIMCJOH_VIS federate). You can also run the SIMCJOH federation over a WAN, in this case you are required to create and set-up a VPN.

SIMCJOH_VIC Stand – Alone Execution: to run SIMCJOH_VIC stand-alone, just double click on the SIMCJOH_VIC executable file included in the SIMCJOH_VIC directory. In stand-alone mode, the SIMCJOH_VIC is provided with a basic graphic user interface that allows testing the SIMCJOH_VIC functionalities. The SIMCJOH_VIC also includes the help button that explains how to use the user interface and the SIMCJOH_VIC functionalities.

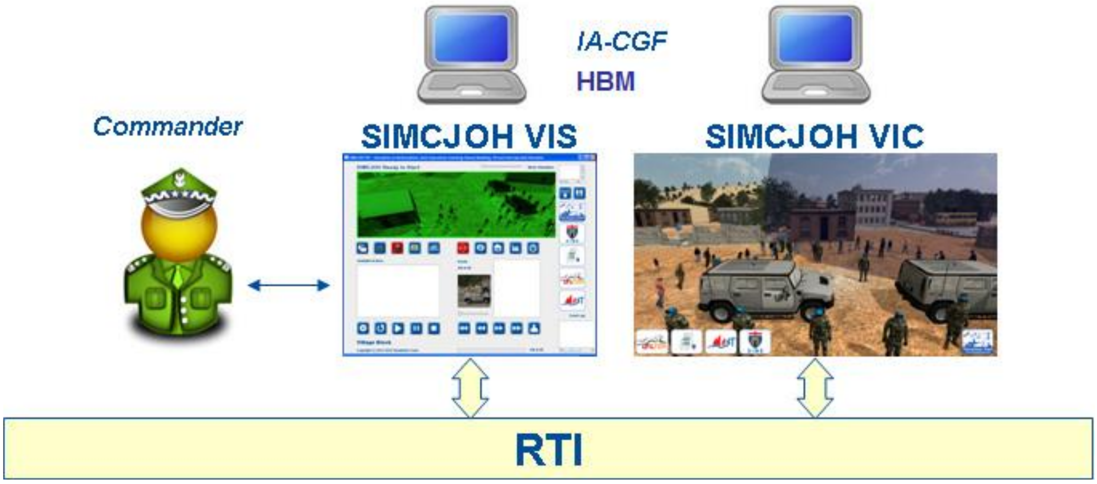


Fig. 96 - SIMCJOH VIS & VIC federated locally

Model Demonstration Test: this section contains the test specifications and the test results of the SIMCJOH_VIC simulator.

Test Configuration: the SIMCJOH_VIC system ran on Windows 8 and was a 64 bit executable. The SIMCJOH_VIC Simulator ran as single federate of the SIMCJOH Federation. This configuration is equivalent to the stand-alone mode but it has been used to test SIMCJOH_VIC capability to join and work as federate of the SIMCJOH HLA 1516-2010 Evolved federation. For the federation the MÄK-RTI Version 4.2 was used. The RTI was running on University of Calabria site. The FOM was based on a RPR2 draft 20 extended by Player Message interactions. The federation used time management with a step size of one correlating to one second of simulation time. SIMCJO H_VIC used a look ahead time of one.

3.4.2 SIMCJOH VIC test sets

The following table reports all the tests that have been executed by using the SIMCJOH_VIC simulator. Each test is then furtherly described in the next sections of this document.

Table 1: Test sets for SIMCJOH_VIC in stand-alone mode

#	Test Set	OK
1	Request Unit to move to Point B	✓
2	Assign an escort enforcement to Negotiator	✓
3	Prepare Goods to be distributed within a Location	✓
4	Distribute Goods within a Location	✓
5	Request Police/Paramilitary forces to Move to point B	✓
6	Request Local Police forces to Support Negotiation	✓
7	Request to conduct Reconnaissance over a Location adopting a specific mode	✓
8	Activate/Deactivate EW Bubble Over the Location	✓
9	Request for training and mentoring activities to Local Police Forces	✓
10	Report on the Status of Population	✓
11	Request Local Police forces to Stop Disorders in a location	✓
12	Request of Helicopters Support	✓

Request Unit to move to Point B

Table 2 reports the test cases conducted for the test #1: Request Unit to move to point B. Two test cases have been simulated: (1) moving a military truck transporting two squads from point A to point B; (2) move a military truck transporting food kits for a CIMIC operation from point A to point B. The results of the test are reported in table 2.

Table 2: test cases for the test #1: Request Unit to move to point B

Test case	Action	Verify	OK	Not OK
1	Request to move two military trucks with two squads from point A to point B	Verify that the military truck moves and arrives to point B	✓	
2	Request to move a military truck transporting food kits for CIMIC operation from point A to point B	Verify that the military truck moves and arrives to point B	✓	

Figures from 1 to 6 show the simulation results of the test case 1 and test case 2. In particular, figures 1, 2, 3 and 4 are related to test case 1 and show respectively:
- the internal view from the truck cockpit while moving from point A to point B;
- the view on the second truck taken from the back of the first truck while moving from point A to point B;
- the view of the two trucks with two squads inside while moving from point A to point B;
- the view of the trucks arrived at point B.

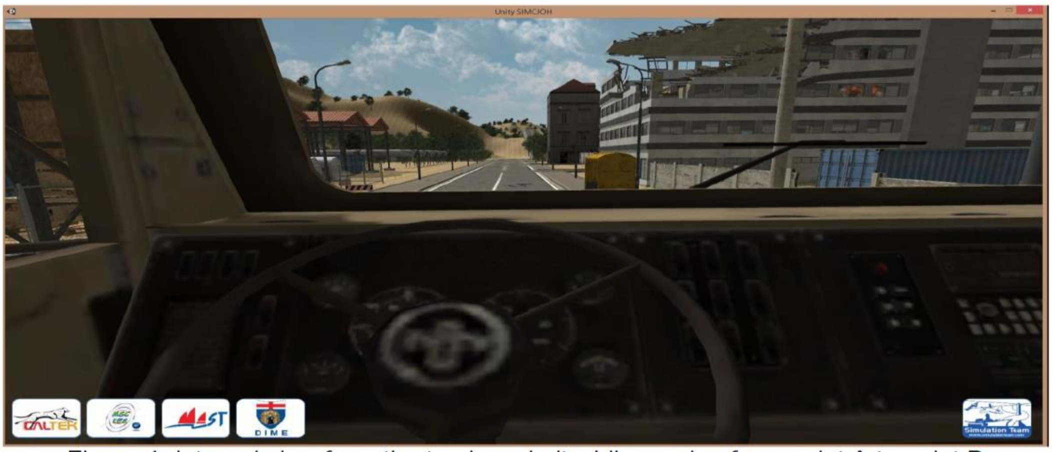


Figure 1: internal view from the truck cockpit while moving from point A to point B


Figure 2: view on the second truck taken from the back of the first truck while moving from point A to point B

Figure 3: view of the two trucks with two squads inside while moving from point A to point B

Figure 4: view of the trucks arrived at point B

Figures 4 and 5 are related to test case 2. In particular, figure 5 shows a truck transporting food kits for CIMIC operations while moving to point B; figure 6 depicts the truck transporting the food kits for CIMIC operations arrived at point B.

Figure 5: truck transporting food kits for CIMIC operations while moving to point B

Figure 6: truck transporting food kits for CIMIC operations arrived at point B

Assign an Escort Enforcement to Negotiator

Table 3 reports the test case conducted for the test #2: assign an escort enforcement to Negotiator. According to the order received an escort including two soldiers moves close to the negotiator.

Table 3: assign an escort enforcement to negotiator.

Test case	Action	Verify	OK	Not OK
1	Assign an escort enforcement to Negotiator	Verify that the escort moves close to the negotiator	✓	

Figures from 7 to 10 show the simulation results of the test case 1. In particular, figures 7, 8, 9 and 10 show respectively:

- the negotiator talking with the village leader;
- a panoramic view of the negotiator talking with the village leader;
- arrival of the escort;
- a panoramic view of the negotiator supported by the escort.

Figure 7: the negotiator talking with the village leader

Figure 8: panoramic view of the negotiator talking with the village leader

Figure 9: arrival of the escort

Figure 10: panoramic view of the negotiator supported by the escort

Prepare Goods to be distributed within a Location

Table 4 reports the test case conducted for the test #3: prepare goods to be distributed within a location. According to the order received the soldiers start preparing goods to be distributed during a CIMIC operation.

Table 4: prepare goods to be distributed within a location

Test case	Action	Verify	OK	Not OK
1	Prepare goods to be distributed within a location	Verify that are prepared to be distributed	✓	

Figure 11 shows goods prepared to be distributed within a location as well as civilians arrival.

Figure 11: goods prepared to be distributed within a location

Distribute Goods within a Location

Table 5 reports the test case conducted for the test #4: distribute goods within a location. According to the order received the soldiers distribute goods during a CIMIC operation within a specific location.

Table 5: prepare goods to be distributed within a location

Test case	Action	Verify	OK	Not OK
1	Distribute Goods within a Location	Verify that goods are distributed	✓	

Figure 12 shows a civilian moving toward the location were the goods are distributed; figure 13 shows a soldier interacting with people that are receiving goods, while figure 14 depicts civilians waiting for good distribution.

Figure 12 – A civilian moving toward the location were the goods are distributed

Figure 13 - A soldier interacting with people that are receiving goods

Figure 14 – Civilians waiting for goods distributions

Request Local Police forces to Move to point B

Table 6 reports the test case conducted for the test #5: Request Local Police forces to move to point B. According to the order received the Local Police moves to point B.

Table 6: request local police forces to move to point B

Test case	Action	Verify	OK	Not OK
1	request local police forces to move to point B	Verify that local police force is moving to point B	✓	

Figure 15 shows the local police forces while moving to Point B.

Figure 15 - Local police forces while moving to Point B.

Request Local Police forces to Support Negotiation

Table 7 reports the test case conducted for the test #6: request local police forces to support negotiation. According to the order received the Local Police forces start supporting negotiation.

Table 7: request local police forces to move to point B

Test case	Action	Verify	OK	Not OK
1	request local police forces to support negotiation	Verify that local police forces support the negotiation	✓	

Figure 16 shows the local police forces close to the negotiator to support negotiation.

Figure 16 – local police forces close to the negotiator to support negotiation

Request to conduct Reconnaissance over a Location adopting a specific mode

Table 8 reports the test case conducted for the test #7: request to conduct reconnaissance over a location adopting a specific mode. In particular, the specific mode used is the Helicopter that fly over the village where the squads are blocked. According to the order received two helicopters fly over the village.

Table 8: request local police forces to move to point B

Test case	Action	Verify	OK	Not OK
1	request to conduct reconnaissance over a location adopting a specific mode (helicopters)	Verify that helicopters are flying over the location to carry out reconnaissance operation	✓	

Figure 17 shows the helicopters that are flying over the location to carry out reconnaissance operation.

Figure 17 – Helicopters flying over the location to carry out reconnaissance operation

Activate/Deactivate EW Bubble Over the Location

Table 9 reports the test case conducted for the test #8: activate/deactivate EW bubble over the location. According to the order received the EW Bubble is activated or deactivated.

Table 9: activate/deactivate EW bubble over the location

Test case	Action	Verify	OK	Not OK
1	activate/deactivate EW bubble over the location	Verify that the EW Bubble is activated or deactivated	✓	

Figures 18 and 19 show a 3D virtual representation of the EW Bubble during after its activation and during its deactivation respectively.

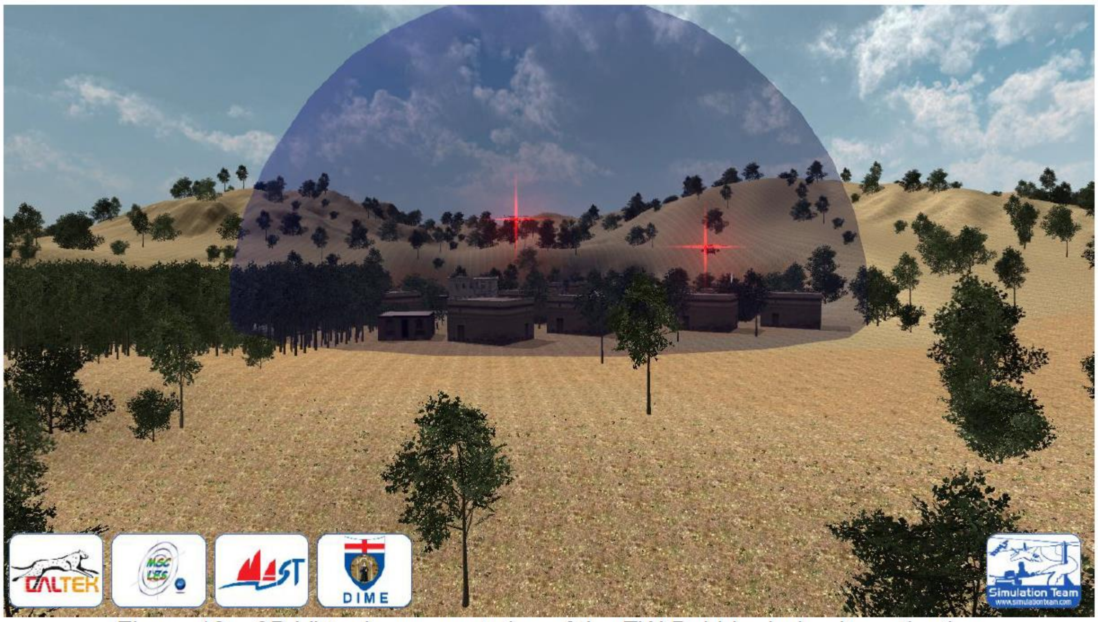


Figure 18 – 3D Virtual representation of the EW Bubble during its activation

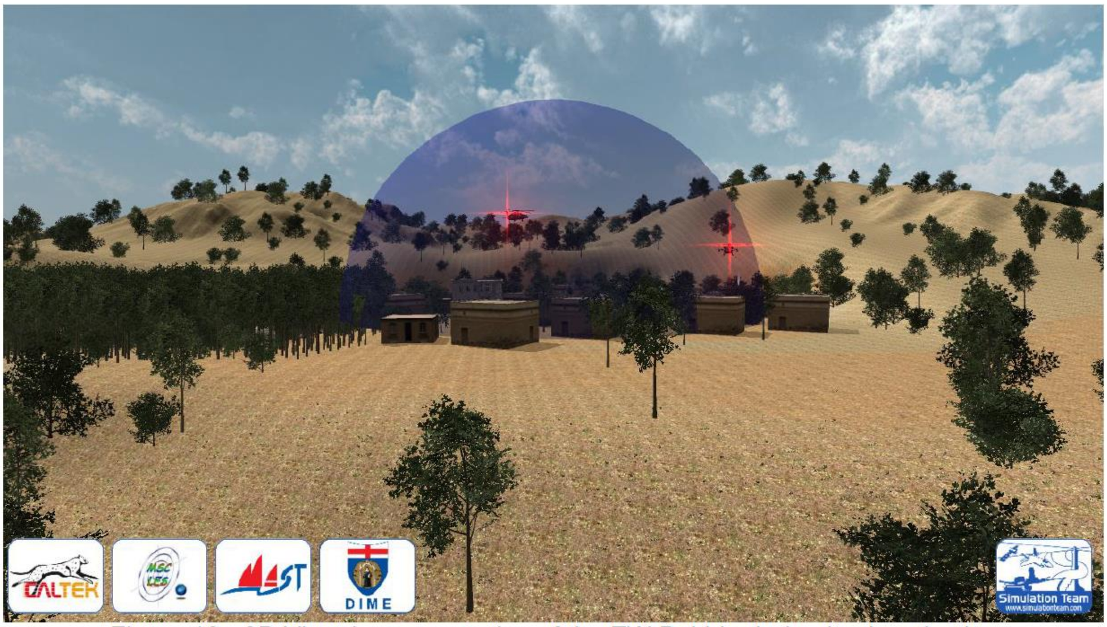


Figure 19 - 3D Virtual representation of the EW Bubble during its deactivation

Request for training and mentoring activities to Local Police Forces

Table 10 reports the test case conducted for the test #9: request for training and mentoring activities to Local Police Forces. According to the order received the Local Forces Police get ready to be trained.

Table 10: request for training and mentoring activities to Local Police Forces

Test case	Action	Verify	OK	Not OK
1	request for training and mentoring activities to Local Police Forces	Verify that Local Police Forces get ready to be trained	✓	

Figure 20 shows Local Police Forces get ready to be trained.

Figure 20 – Local Police Forces get ready to be trained

Report on the Status of Population

Table 11 reports the test case conducted for the test #10: report on the status of population. According to the reported requested, the status of the population is reported.

Table 11: report on the status of population

Test case	Action	Verify	OK	Not OK
1	report on the status of population	Reporting on the status of the population	✓	

Figures 21, 22, and 23 show three different example of population status in the area of the village where the squads are blocked, namely:

- small crowd, no social tension;
- middle crowd, no social tension;
- large crowd, increase of the social tension.

Figure 21 – Small Crowd of civilians, no social tension

Figure 22 - Middle Crowd of civilians, no social tension

Figure 23 - Large Crowd of civilians, increase of social tension

Request Local Police forces to Stop Disorders in a location

Table 12 reports the test case conducted for the test #11: request local police forces to stop disorders in a location. According to the order received the local police forces start stopping disorders in a location.

Table 12: request local police forces to stop disorders in a location

Test case	Action	Verify	OK	Not OK
1	request local police forces to stop disorders in a location	Verify that the local police forces start stopping disorders in a location	✓	

Figure 24 shows the local police forces while moving through civilians to stop disorders in the area where the squads are blocked.

Request of Helicopters Support

Table 13 reports the test case conducted for the test #12: Request of Helicopters Support. According to the order received the helicopters arrive in the location where the support is needed.

Table 13: Request of Helicopters Support

Test case	Action	Verify	OK	Not OK
1	Request of helicopters support	Verify that the helicopters arrive in the location where the support is needed	✓	

Figure 25 shows the helicopter flying over the village where the squads are blocked.

Figure 25 - The helicopter flying over the village where the squads are blocked

Request to cordon the village

Table 14 reports the test case conducted for the test #13: Request to cordon the village. According to the order received different squads cordon the village.

Table 14: Request to cordon the village

Test case	Action	Verify	OK	Not OK
1	Request to cordon the village	Verify that the village is cordoned	✓	

Figure 26 shows different squads and vehicles while cordoning the village by blocking the entrance road.

Figure 26 – squads and vehicles while cordoning the village by blocking the entrance road.

Request to send a negotiator

Table 15 reports the test case conducted for the test #14: Request to send a negotiator. In accordance with the order received, the negotiator is sent for starting negotiation with the village leader.

Figure 26 shows different squads and vehicles while cordoning the village by blocking the entrance road.

Figure 26 – squads and vehicles while cordoning the village by blocking the entrance road.

case				OK
1	Request to send a negotiator	Verify that the negotiator is sent and starts the negotiation	✓	

Figure 27 shows the negotiator while talking with the village leader in the area where the squads are blocked.

Figure 27 – negotiator while talking with the village leader in the area where the squads are blocked

3.5 Computer Generated Forces & Virtual Assistants Experimental Test plan - SIMCJOH VIS demonstration

The Computer Generated Forces (CGF) have been implemented in SIMCJOH_VIS simulator and SIMCJOH VIC. The simulator operates in federated mode between SMICJOH_VIC and SIMCJOH_VIS; SIMCJOH_VIC allows to present the dynamic situation and to manage the behaviour of individual virtual entities, while SIMCJOH VIS focuses on the CGF simulation. A test plan has been prepared to evaluate the behaviour of CGF in order to be used during the final demonstration.

3.5.1 Computer Generated Forces

SIMCJOH_VIS CGF are based on IA_CGF (Intelligent Agent Computer Generated Forces) developed by Simulation Team. CGF can be operative also in stand-alone mode, by using meta-model in SIMCJOH VIS; in this case the scenario evolves based on CGF actions, while automatic reporting provided by the Virtual assistants represent the monitoring of the scenario evolution. When federated with SIMCJOH_VIC the virtual simulation is dynamically aligned with the overall situation controlled by SIMCJOH_VIS CGF. In SIMCJOH, CGFs reproduce the

Virtual Assistants in charge of reporting to the Commander and give execution to his decisions.

3.5.2 Virtual Assistants model test plan

Boundary conditions such as weather and media actions affect the elements to finalize the proposal, the decisions and the operational plans developed by the CGF. The CGFs simulates the Commander Staff (represented in the simulation by Virtual Assistants – VAs) and its reaction to the escalation of the social tension in fictional village in South Eblanon. For the experimental test, it is considered the case of village Block, with the – VAs) behaviour of rioters surrounding the squad and population evolves over time. Based on squad report and other information source, the Virtual assistants take care of addressing the situation and proposing the Commander available course of actions; the change on the situation is dynamic and results in the necessity to adapt to a mechanism of action/reaction (i.e. social tension change, non-availability of military assets from Local Authority, etc.). The Virtual Assistants enable possible changes and options based on request by the Commander; in addition, Virtual Assistants controlled by the CGF could decide to adapt dynamically respect the course of action adopted by the Commander/player.
The Virtual Assistants currently cover different roles:

- VA JS Chief of Staff
- VA G2 Intelligence
- VA G3 Operations
- VA G4 Logistics
- VA G7 Training
- VA G9 CIMIC
- VA LEGAD Legal Advisor
- VA POLAD Political Advisor
- VA PAO Public Affair Officer
- VA CULAD Cultural Advisor

Each Virtual Assistant collect data and complete a report as result of scenario awareness respect the specific issue to be addressed; these elements support Commander decisions; as soon as decision is adopted the Virtual Assistant takes it

in place and adapt the specific COA to the dynamic evolution of the scenario while he reports updates back to the Commander. In case of problems that require drastic changes, alert is generated and communicated to the commander (e.g. helicopter malfunction, denied support from local authorities, etc.).
The different Decisions analysed by the CGF driving the Virtual Assistants are finalized for the demonstration in MEL/MIL1 Village Block, related to the issues described below.

<u>Decision Zero: Village Block Analysis and Alternative COAs</u>
The report self-adapt dynamically to the situation and provides four alternative COAs to be adopted by Commander; the Virtual Assistant in charge of it is the Chief of Staff, coordinating all other Virtual Assistants.

<u>Decision 1: Recce Activation</u>
Deals with the possibility to activate Recce by using different resources such as Helicopters, Special Forces and UAV; these are based on availability of these assets and their effectiveness respect the current situation. G3 Virtual Assistant is in charge of this item.

<u>Decision 2: Air Asset Activation</u>
This decision is devoted to identify how many and what specific air asset to use within those available in the brigade under the Commander and includes different Helicopters and UAV (if available). G3 Virtual Assistant is in charge of this item.

<u>Decision 3: Dispatch UNIFIL Helicopters</u>
This decision is devoted to request additional support to UNIFLI resources; in this case Ghana (one of the UNIFLI contributing nations) has helicopters that could be required to integrate Italian Units or to address problems due to unavailability of our assets. Chief of Staff Virtual Assistant is in charge of this item.

<u>Decision 4: Helicopter Evacuation</u>
Based on the situation of the scenario (i.e. effective presence of snipers and hostile forces, available space for landing etc.) it could be considered to evacuate the blocked patrol trough air (helicopters); however, this action involves significant

risks and should be properly evaluated as well as planned in case of activation. G3 Virtual Assistant is in charge of this item.

Decision 5: Air Support

There the possibility to call an Air Support operation in order to release the pressure over the blocked squad; this brings however risk of collateral damage, i.e. igniting a reaction from the population. G3 Virtual Assistant is in charge of this item.

Decision 6: Identify and dispatch an envoy to act as Negotiator

It is possible to run the negotiation in the village by using different subject such as the squad leader, the CIMIC Responsible of last action in the village, a CIMIC Coordinator or Local Authorities; the perception of the current situation and reports about previous activities (i.e. success level of previous CIMIC) have to be considered in conjunction with the capabilities of the different subjects and with their readiness to respond to the crisis; in general estimations of these elements should be considered as decision elements based on the reports prepared by the Virtual Assistants. Chief of Staff Virtual Assistant is responsible of this item.

Decision 7: Goods Delivery

A quick CIMIC operation for goods delivery can be activated to support the condition, therefore the way to deliver it is critical; it could be possible to carry out it on site concurrently with the negotiation or postpone after the completion of the crisis; population will react to this alternatives eventually creating a crowd around the area that could result dangerous; therefore the impact of concurrent distribution could be more effective, so a decision should be made based on risk analysis; the Virtual Assistant responsible of the CIMIC is in charge of this item.

Decision 8: MEDEVAC

During the Scenario evolution, the rioters could generate WIA (Wound in Action) among the soldiers of the blocked squad, thus requiring a Medical Evacuation (MEDEVAC). In this case his situation evolves dynamically and could degenerate; MEDEVAC could be a solution, therefore the decision to proceed or not as well as the way to complete it is critical and relies on stochastic factors, so a risk analysis should be completed. In this case the use of Helicopters or ground units are possible alternative for the execution; G3Virtual Assistant is in charge of this item.

Decision 9: Authorizing Use of Force

This is a very drastic decision considering the civil presence into the urban area and the very high risk of collateral damages; therefore, some scenario evolution could lead to this conditions; in the model are used to compute hitting and damaging probability by applying Montecarlo Techniques and Lanchester's equations. G3 Virtual Assistant is in charge of this item.

Decision 10: Helicopter Deterrence

It is possible to use the Helicopters in way to create deterrence; flying altitude and modes affect the impact on the population with positive effects in term of deterrence, but also risks as well as impact in terms of stress and fear on population. G3 Virtual Assistant is in charge of this item.

Decision 11: Blocked Unit

Orders could be transmitted to the blocked squad if communications are available. These corresponds to different alternatives, listed below in order of aggressiveness:

Stand by (the default option): neutral;

Keep Position: neutral

Raising Weapons: low aggressiveness;

Shoot in Air: medium aggressiveness;

Fire at Will: high aggressiveness;

Consign Weapons: i.e. the surrender of the Squad.

Especially the "Fire at Will" option has to be considered the least feasible together with "Consign Weapons", because both are contrary to the mission mandate and so corresponding to non-accomplishment of the game objective. However, in condition of an extreme crisis the irrational behaviour of an individual or a group can overcome the moral restrains and the military training, resulting in actions contrary to the law. For such reasons, even though the G3 Virtual Assistant is normally in charge, IA-CGF controlling the squad, under certain conditions and based on the gravity of the situation, could decide to supersede and so act by itself.

Decision 12: Local Police Information

The engagement of local authority could be done based on an evaluation of their reliability and effectiveness; this is a pretty crucial element that could result into a support, but also lead to further problems. Chief of Staff Virtual Assistant is in charge of this item.

Decision 13: CIMIC After the Event

It is possible to activate CIMIC on the following months to mitigate the effect of the event, therefore during the simulation an estimation of this action should be considered as well as its impact on the future scenario evolution; CIMIC Virtual Assistant is in charge of this item.

Decision 14: PSYOPS on Radio

Activation of PSYOPS on Radio transmission is a possibility and a decision on the related effort and quickness should be taken to optimize time response versus impact on the situation. PAO Virtual Assistant is in charge of this item.

Decision 15: PSYOPS on Leaflets

Activation of PSYOPS by dropping available leaflets from helicopters is a possibility; in case is necessary to address it in time to board such material on the helicopters. PAO Virtual Assistant is in charge of this item.

Decision 16: PSYOPS on Loud Speakers by Ground Units

Activation of PSYOPS by Loud Speakers from Ground Units is an option; therefore, previous IDF use of such techniques could ingenerate controversial reactions from the population. PAO Virtual Assistant is in charge of this item.

Decision 17: Arrest Agitators

This is a quite drastic decision that could increase the tension. It could be performed for real or threatened; however, UNIFIL mandate don’t authorize it. The LEGAD Virtual Assistant is in charge of this item.

Decision 18: creation of an EW "Bubble"

The activation of an Electronic Warfare "Bubble" (meaning with that the intentional disrupting of communication achieved by dedicate jamming devices) could interdict the use of mobile phones among the population, and so achieve the "electro-magnetic" insulation of the village. This could be an option, in order to interrupt the C2 chain of the rioters and so (possibly) contributing to cool down the tension. However, again, UNIFLI mandate don't authorize EW in the area; in addition, the social tension instead could increase, and local and international media later on will definitely deliver critics over the news. G3 Virtual Assistant is responsible of this item, but LEGAD contributions is requested as well.

Decision 19: Press Release

Issuing a press conference or a declaration addressing the situation by UNIFLI officials - before the local media arrive on the spot - is a critical issue on the path of the crisis's resolution. The Public Affair Officer (PAO) Virtual assistant is in charge of this Item.

Decision 20: Negotiation Target identification

To properly identify the target for negotiating about village block it is a critical issue; demonstration Leaders are the first choice, even though they could result not to be the right people to address, while a Political or Religious Leader can be. The Intelligence reports are critical to properly identify this situation. Chief of Staff Virtual Assistant is in charge of this item.

Decision 21: Ground Support

This decision is devoted to identify how many and what specific ground unit to use within those available; the brigade reserve as example could make available up to two companies, but it should be decided if it is enough to use just 1 or 2 platoons. However, a massive show of force can increase deterrence, but it can heat up as well the tension in the village. G3 Virtual Assistant is in charge of this item.

Decision 22 Intelligence Updating

Additional intelligence updates should be taken to optimize time response during the crisis. G2 Virtual Assistant is in charge of this item.

In conclusion, each time a critical event occurs, the CGF face it and analyse possible reaction, within the required time necessary to elaborate proposals for the Commander. The Commander then will adopt one of the decisions (from 1 to 22) and accordance with it, further resources are allocated by the simulator with the required time. So the test plan of these models combines the generation of Reports by the Virtual Assistants versus the scenario evolution and the application of decisions.

3.5.3 SIMCJOH VIS demonstration test

The demonstration test was conducted on SIMCJOH VIS in stand-alone about the CGF and Monitoring System during the Village Block on MEL/MIL1 in stand-by mode. Initial Conditions and boundary conditions are default for MEL/MIL1; no change are required on the input parameters or in configuration respect SIMCJOH VIS default configuration. The player activates the scenario clicking on “Simulation”; then activate the run by clicking “run button”, the simulator generates a block in a village. The player again selects a Course of Action as soon as the CGF Virtual Assistants are ready to report; information is summarized in Power Point dynamically created on SIMCJOH VIS. At the beginning however the Virtual Assistants don’t have elements about the crisis; therefore, as soon as the crisis evolves, the VAs begin to analyse the problem, and simulation time is consumed, as reported by the red bar, which provides an estimation of work needed to finalize a course of action to address the crisis (see figure below). The staff submit the possible alternatives to the Commander, and as soon as the decision is finalized, they will activate the Corresponding COA using their time and resources as outlined by the blue advance bar (see figures below)

Fig. 97 – CGF VAs waiting for the arrival of information

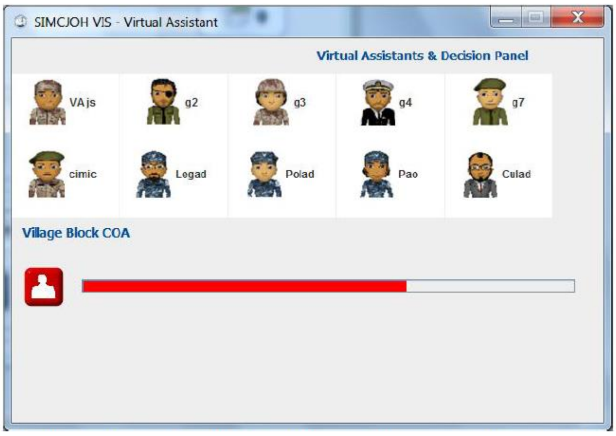


Fig. 98 – CGF VAs are elaborating vs the scenario evolution

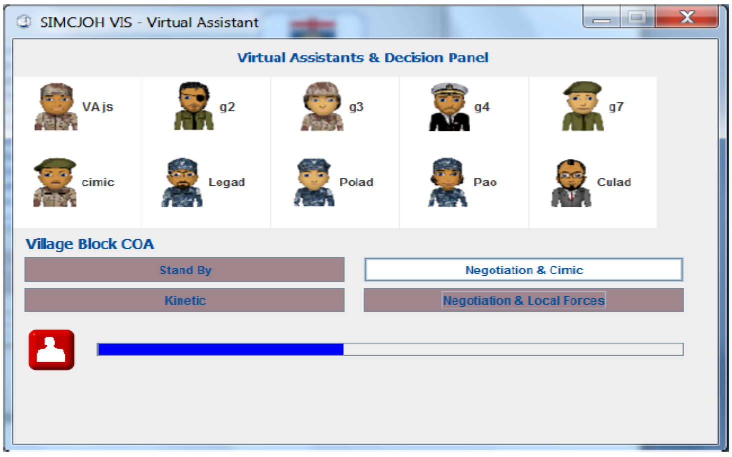


Fig. 99 – CGF Vas preparing the execution

Here we have some example of dynamic situation monitoring and CGF report.

Fig. 100 – Reports produced by CGF VAs

As example, respect to the choice "Negotiation and CIMIC" and "Send a negotiator", we have the following:

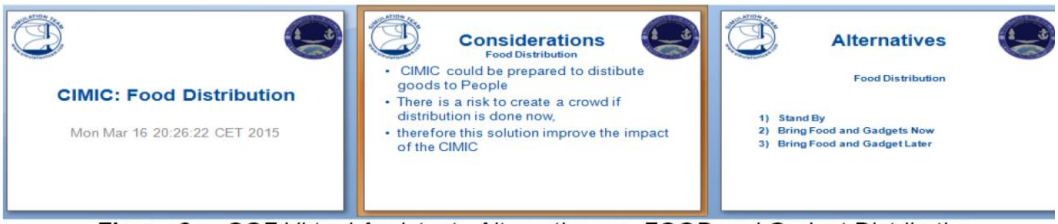


***Figure 6a** - CGF Virtual Assistants Alternatives on FOOD and Gadget Distribution*

If SIMCJOH VIS is federated with SIMCJOH VIC the activation of Immediate CIMIC produces the starting of the virtual trucks as proposed into the following image


***Figure 6b** – Effect in Virtual World of CGF Virtual Assistants Plan Execution*

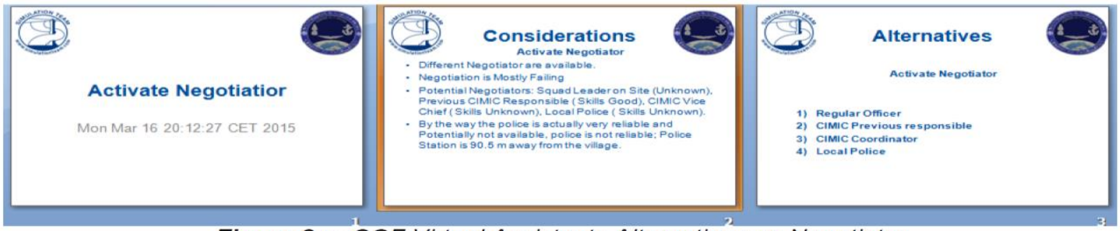


***Figure 8a** - CGF Virtual Assistants Alternatives on Negotiator*

If SIMCJOH VIS is federated with SIMCJOH VIC, the decision on Negotiator produces a change in the virtual world as proposed into the following image


***Figure 8b** – Effect in Virtual World of CGF Virtual Assistants on Negotiator*

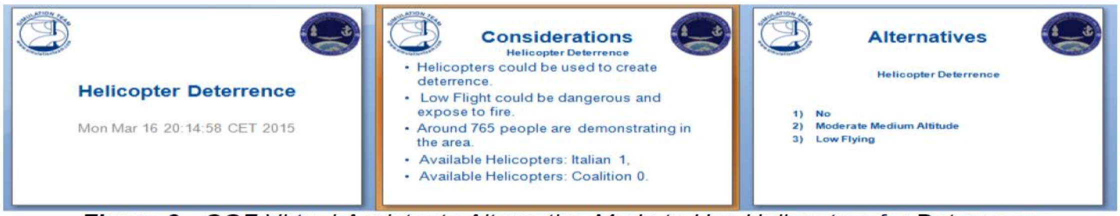


***Figure 9** - CGF Virtual Assistants Alternative Mode to Use Helicopters for Deterrence*

3.6 Results of Experimental Analysis

The SIMCJOH experimentation allows to identify the behaviour of target functions mapped by the simulator; this analysis represent an example of how Design of Experiments and Sensitivity Analysis allows to evaluate the impact of the independent variables on the target functions
SIMCJOH Experimentation has involved military users and subject matter experts to:

- collect user requirements;
- develop and validate SIMCJOH conceptual models;
- define the specific mission environment implemented in SIMCJOH Demonstrator;
- validate the Demonstrator functions and features including interoperability capability;
- test SIMCJOH Demonstrator and analyse simulation results.

Concerning with the experimentation execution and the simulation results, the partners provided an example of techniques and methodologies to be used for studying results consistency.
In particular Mean Square Pure Error and Sensitivity Analysis are carried out.
The analysis of MSpE (Mean Square pure analysis) is required as measure of the variance of the target functions among replicated runs over the same boundary conditions. By this approach it becomes possible to identify the number of replications and the simulation duration able to guarantee a desired level of precision; MSpE values in correspondence of these experimental parameters determines the amplitude of the related confidence band.
The Experimentation has been developed over the Village Block MEL/MIL; the target function on this simulator are addressing the following variables:

- Scenario Duration
- Final Results (Success / Failure)
- Demonstration Size (Average, Min, Max)
- Demonstration Final Condition Situation
- Military Coalition Casualties
- Civil Casualties

- OPFOR Casualties
- Friendly Force around the Crisis Area
- Foe Force around the Crisis Area
- Friendly Deterrence on Crisis Area
- Foe Deterrence on Crisis Area
- WIA Situation
- Squad Status
- MEDEVAC Result
- Evacuation Result
- Impact on Domestic Media
- Impact on Local Media
- Press Release Readiness
- Stress Level on the Village
- Fear Level on the Village
- Fatigue Level on the Village
- Aggressiveness Level on the Village
- UNIFLI Caveat Respect on Fire
- UNIFLI Caveat Respect on Arrests
- UNIFLI Caveat Respect on EW Bubble
- Communication Shut Down by EW
- Village Block Situation
- Squad Final Result
- CIMIC Status
- After Action CIMIC Status
- Radio PSYOPS Status
- Leaflets PSYOPS Status
- Loud Speakers PSYOPS Status
- Combat Status in the Village
- List of All taken Decisions

All these variables are affected by the decisions that could be taken by the Commander/player (e.g. selected COA, Intelligence operations, CIMIC Planning,

etc.) and by the boundary conditions (e.g. weather, hostile forces, history of actions on crisis area, skills of available resources, etc.)
Mean Square Pure Error are carried out for different Commander Decision:

- Stand By
- Negotiation & CIMIC
- Kinetic
- Negotiation & Local Forces

The developers applied the use of Design of Experiments in order to estimate the impact of stochastic variables on the target function.
In this case the developers used as main independent variable the Commander decision about the overall COA on the scenario:

- Stand By
- Negotiation & CIMIC
- Kinetic
- Negotiation & Local Forces

The approach is based on ANOVA (Analysis of Variance); in particular, it is proposed the analysis of MSpE (Mean Square pure analysis) that is an effective measure of the experimental error due to the stochastic elements present in the simulators; indeed, MSpE provides a measure of the variance of the target functions among replicated runs over the same boundary conditions just by changing the random seeds of the random generators. By this approach it becomes possible to identify the number of replications and the simulation duration able to guarantee a desired level of precision.
MSpE values in correspondence of these experimental parameters determines the amplitude of the related confidence band:

$$MSpE\ (t,\ n_0) = \frac{\sum_{i=1}^{n_0} x_i\ (t) - \bar{x}(t)}{n_0}$$

$$\bar{x}(t) = \frac{\sum_{i=1}^{n_0} x_i\ (t)}{n_0}$$

t	simulation time
no	number of replications with same boundary conditions and different random seeds
MspE (t,n_o,)	Mean Square pure Error at t time

In fact, the MSpE allows to quantify the experimental error due to influence of the stochastic components respect the required replications or durations for obtaining a stabilization; by this approach it becomes possible to estimate the confidence band on the different target functions For instance, considering the Aggressiveness Level of Population related to the 4 different commander decisions, the MSpE (Mean Square pure Error) was computed by carrying out replicated runs over the same boundary conditions

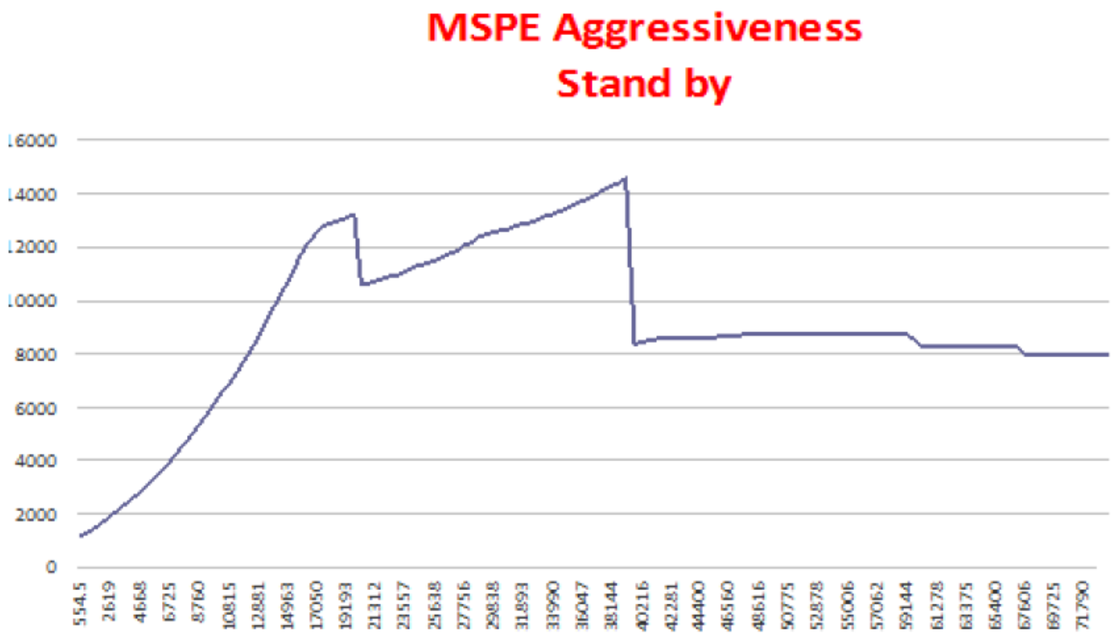


Figure 1: Decision to Stand By during the Crisis– Stand By

The Aggressiveness is expressed as pure number and the Figure 1 provides an estimation of his variance along the simulation as well as the stabilization at during final phases of the simulation.

In following figures multiple runs are compared for the different evolution of this scenario; different end states could be approached during the simulation due to stochastic components therefore final achievements results consistent based on MSpE Analysis.

A further analysis has been conducted by measuring the Number of demonstration during the simulation, considering the four different possible Commander decision respect the main COA during the game.

In the following picture the result of the MSpe considering 10 runs is reported:

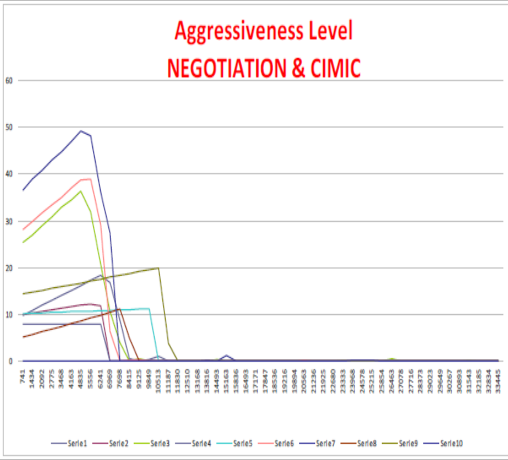


Figure 2: Option 1 – Negotiation & CIMIC: Results of Different Runs

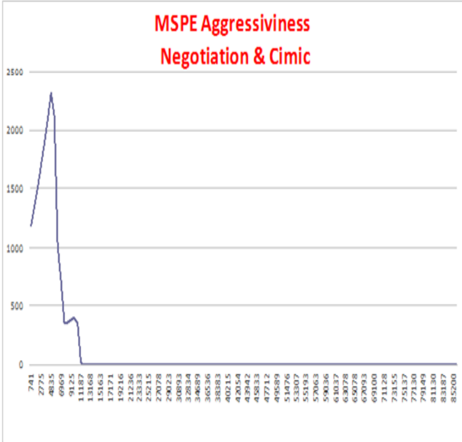


Figure 3: Option 1 – Negotiation & CIMIC - MSPE

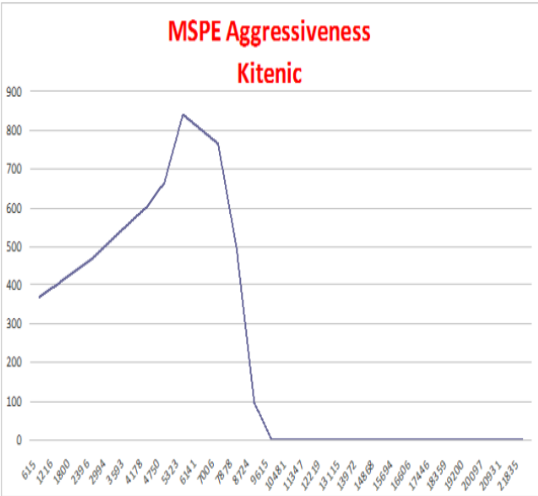


Figure 4: Option 2 – Kinetic MSPE

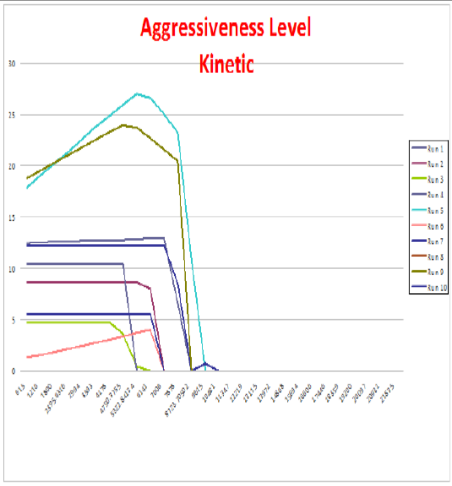


Figure 5: Option 2 – Kinetic Replicated Runs

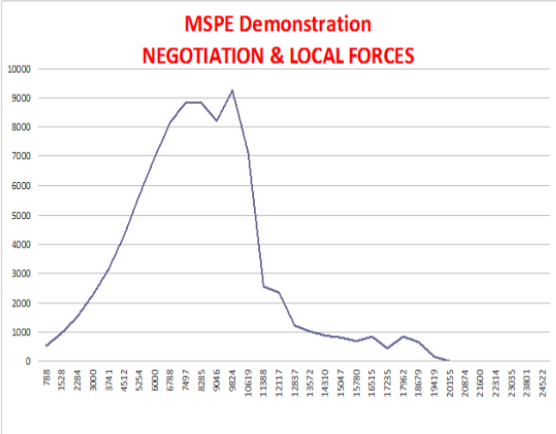


Figure 6: Option 3 – Negotiation & Local Forces MSPE

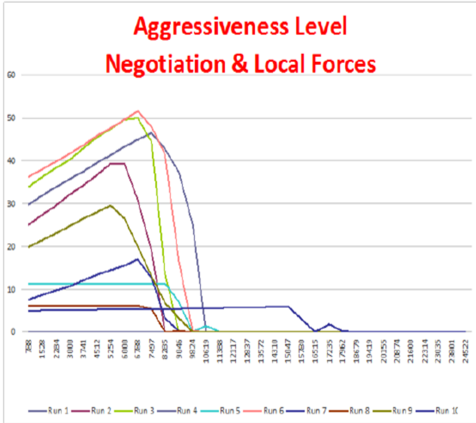


Figure 7: Option 3 – Negotiation & Local Forces Replicated Runs

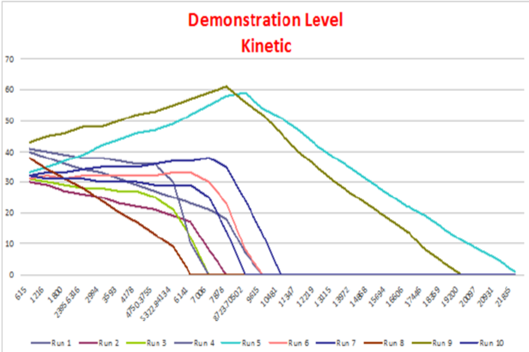


Figure 8: Option 2 - Kinetics different End States - Number of Demonstration

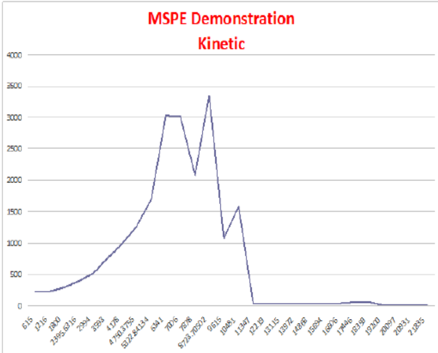


Figure 9 Option 2 - MSpe among Converging Runs

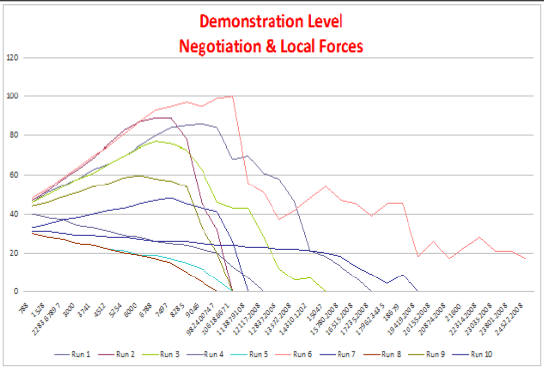


Figure 10: Option 3 - Negotation and Local Forces - Number of Demonstration

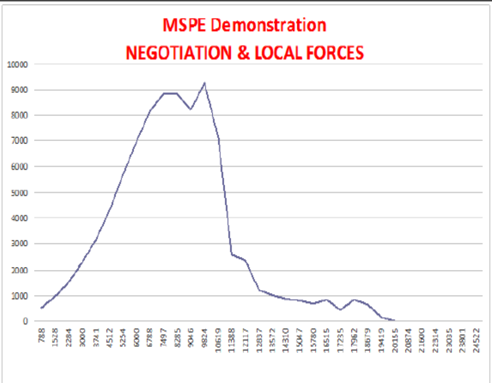


Figure 11: Option 3 - Negotiation & Local Forces - Number of Demonstration MSPE

By applying Design of Experiments it could be conducted a test on the influence of the independent variables respect the target functions.

A sensitivity analysis on the effect of the different decision on simple scenario with limited interactions is proposed in figure 12a, 12b.

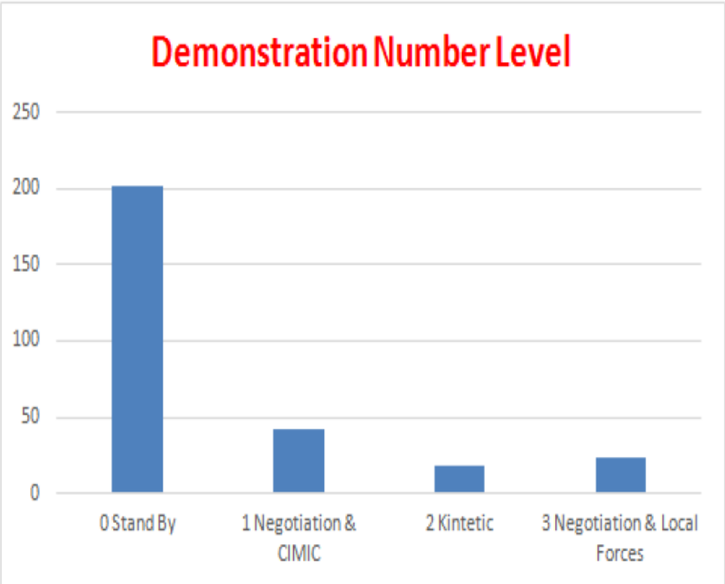


Figure 12a: Sensitivity of the Main Decision on Demonstration Average Size

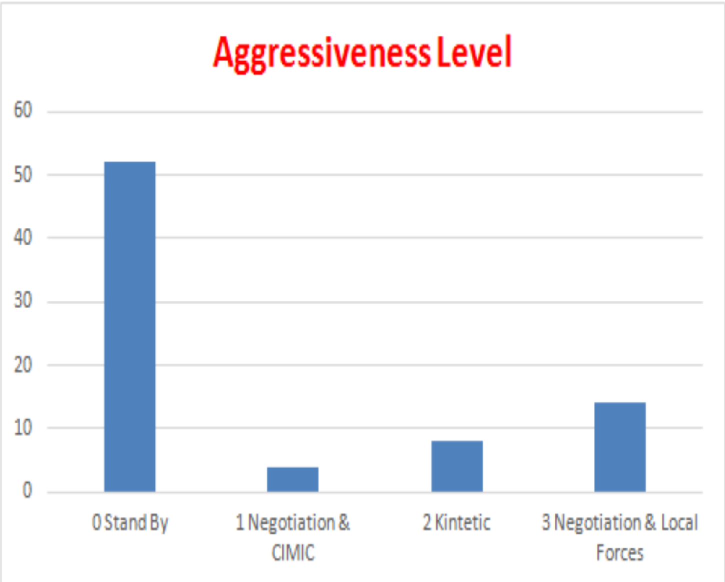


Figure 12b: Sensitivity of the Main Decision on Aggressiveness Level

3.7 V&V applied to simulations involving human behaviour modelling

This paragraph proposes the methodologies applied to complete VV&A (Verification, Validation and Accreditation) of interoperable simulators to be used in an HLA federation to address Multi Coalition Joint Operations in scenarios affected intensively by human factors. A case study (SIMCJOH) it is provided, with an overview of the different methodologies used and the processes carried out along the entire life cycle of the federation development. The example represents a quite challenging context considering the simulation of the human behaviours and the multiple use modes that move from CAX federate to intuitive application for being used directly by Commanders and their staff.

3.7.1 Verification, Validation and Accreditation (VV&A)

VV&A is recognized as, among few, one of the most critical element in simulation project (Amico, Guha and Bruzzone, 2000; Youngblood et al. 2000; Roza et al. 2012; Kim et al. 2015). In a few words, Validation is referred to as the process to ensure that the right M&S assets is built for the intended use (i.e. M&S validity); Verification is the process to ensure that the M&S asset is built right (i.e. M&S correctness). Accreditation (a concept which is often underestimated), represents the corner stone to guarantee the use of simulator, since it is the official certification that a model, simulation, or federation of models and simulations and its associated data are acceptable for use for a specific purpose (IEEE 1997). A top simulation expert with very large experience in industrial application and also in defence, was used to say that “Simulation Failure is usually not due to bad model development, but by missing the trust of the decision makers that should use it to take multi-million dollar decisions” (Williams 1999). Indeed, it is evident that a decision maker should develop trustiness in the capabilities as well as knowledge in the limits of the simulators that is supposed to use (McLeods, 1984). In facts simulation requires significant efforts to be developed and it is usually applied to challenging problems where the decision could affect human life, big quantities of money, important consequences and even personal career (Mosca et al. 1994).
In order to deal with VV&A issues, from 2014 to 2018 NATO created Modelling and Simulation Group (NMSG) 139, “Modelling and Simulation (M&S) Use Risk

Identification and Management". MSG 139 was tasked to define and provide an initial implementation of a roadmap to support the development and employment of a generic methodology, methods and techniques for M&S use risk identification, and analysis and to balance M&S use risk with resources applied to M&S verification and validation (V&V). The work of the group was formalized as the M&S Use Risk Methodology (MURM); on that regard MSG 139 analysed the capability of MURM to balance risks with costs and to provide a mean for risk identification and mitigation.

In the context of the MURM, M&S use risk is defined as:

The probability that inappropriate application of M&S results for the specific intended use will produce unacceptable consequences to the decision maker.

The approach taken has been to translate this definition into mathematical logic used to calculate M&S use risk on a requirement-by-requirement basis.

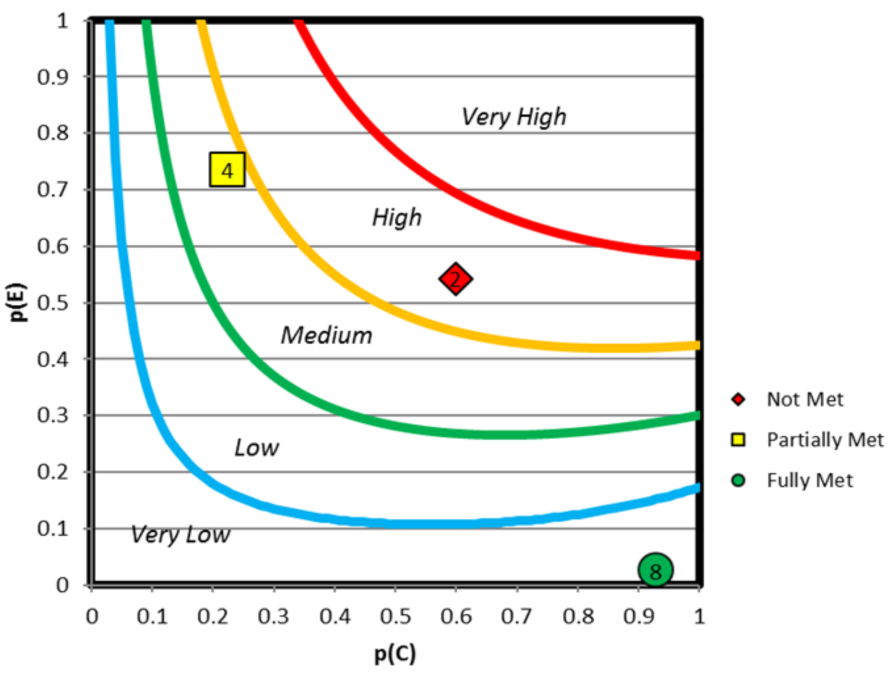


Fig. 101 - M&S Use Risk Plot

The derivation of the methodology is based on coherent mathematical concepts that minimize unintended bias and establishes an explicit relationship to the V&V process and products. The MURM can be useful at several stages of the M&S development process. Upon the conclusion of the work carried out by MSG 139 (April 2018), the proposed way ahead has been to develop an international standard, subject to configuration management and change control, through the Simulation Interoperability Standards Organization (SISO), using its Product Development Group (PDG) process.

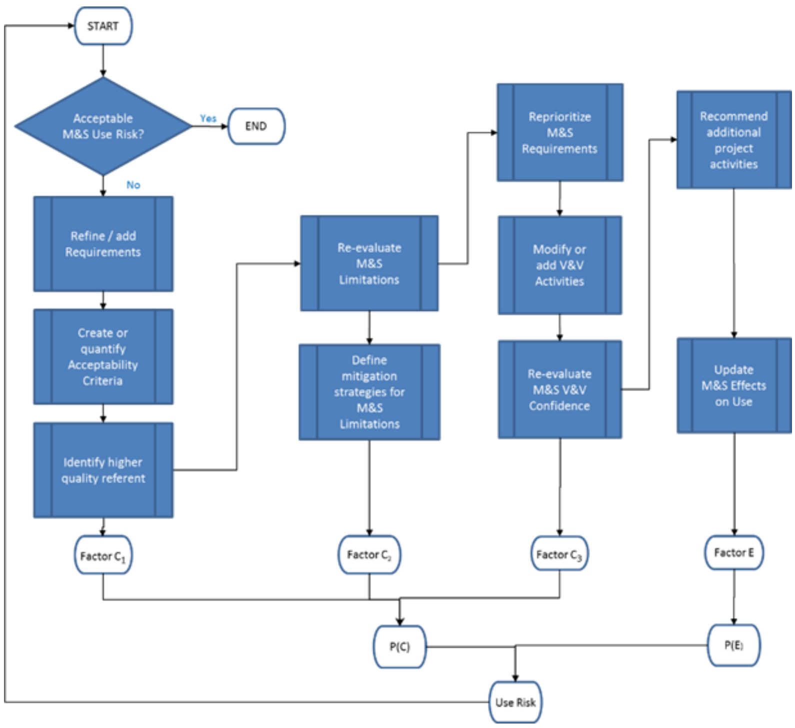


Fig. 102 - Process to Reduce Unacceptable Levels of M&S Use Risk

However, it is fundamental to involve the users in the development process to guarantee that they will trust the simulation and its results, also in case of critical decisions (Bruzzone et al. 2001b & 2002). In facts the decision makers should use simulation for decisions, based on the confidence that they achieved along the VV&A processes by their engagement and understanding of the models and simulator capabilities. It is evident the necessity to engage them since the beginning of development phases, for instance when the simulation goals are defined as well as the main factors and boundary conditions (Balci, 1994; Balci et al. 1996). In order to succeed in this case, it is fundamental to be able to combine users, SMEs and simulation scientists into an effective team that share information and acquire a clear picture of simulation capabilities and limits based on intuitive and measurable achievements, even without entering into the technical details of the algorithms (Amico, Guha, Bruzzone, 2000). The case of simulation for training is a classic example where these principia should be applied, because in absence of full trustiness the impact of simulation training sessions results drastically downgraded, and training objectives risk to be not achieved (Bruzzone & Massei 2017a; Bruzzone et al. 2017b). Considering such aspects, it is very important to properly address the simulation development process matching it with the VV&A activities. Therefore, this aspect becomes very challenging in case of complex models, among these the human behaviour models represent probably one of the most-hard case considering the difficulty to have reliable data and proper model representing both emotional and rational elements. In the next paragraph we refer to the case of SIMCJOH VIS & VIC (Simulation of Multi Coalition Joint Operations involving Human Modelling – Virtual Interoperable Simulation & Virtual Interoperable Commander) simulators, both developed to serve as core engine of SIMCJOH project (Bruzzone et al. 2015b).

3.7.2 VV&A Principles and Criticalities

As already mentioned, Verification Validation and Accreditation (VV&A) represents one of most crucial elements of simulation development, both in decision making and military training domains. In general, V&VA uses consolidated methodologies and procedures since its foundation, and has further developed in a well-defined set of procedures and methodologies (McLeods 1984; Balci et al. 1996; Youngblood et al. 2000; Roza et al. 2012; DoD MIL-STD-3022, 2012; MSG 139, 2018). Along the years, different tentative have been made in the effort to formalize a standard in this sector: however, the high degree of tailoring required to successfully apply VV&A allowed just to define best recommended practices and guidelines as it happen with FEDEP and DSEEP (IEEE 2003, 2011). In particular, one of most successful attempts is embedded in the IEEE 1516.4 best practice; this document provides the description of all consequent conceptual phases of the VV&A efforts, which are overlaid inside FEDEP/DSEEP correspondent phases.

Each phase is articulated into subsequent elementary activities which are then building the different chapters of the VV&A document: Accreditation plan, V&V plan, V&V report and Accreditation Report.

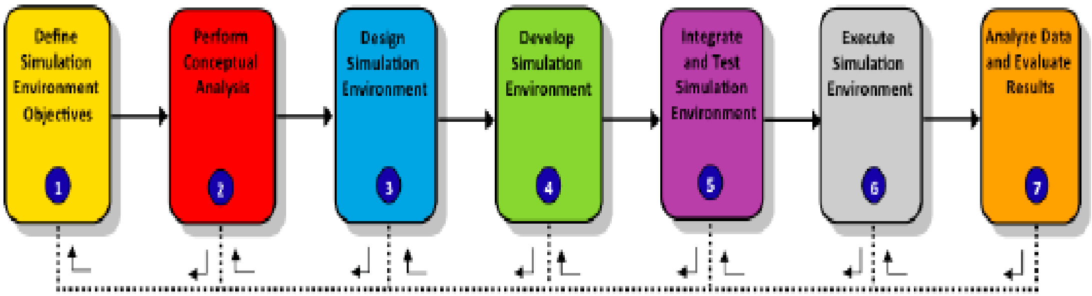


Fig. 103 – DSEEP process for simulation interoperability (from HLA Tutorial 1.0, Pitch Technologies, Sweden 2002)

The IEEE 1516.4 supports the process by providing a clear description of the temporal execution of the different V&V activities; vice versa, the MIL-STD-3022 standard as well as the 5000.61 Instruction have been developed by the US M&S Coordination Office in order to provide templates of the different VV&A documents as well as lists for definitions and concepts to be elaborated during development of simulators and relative V&V. Both approaches are paying attention to support the coordination of the multitude of different actors usually involved in the development V&V and use of the simulators. Because of the similarity and the synergy between the 3022 and the 1516.4, the two document mostly complete each other, even though some differences are present making specific difference in the two approaches; the main is that the MIL STD 3022 is developed for Stand Alone Simulators, while FEDEP and DSEEP are mostly focused on VV&A of federations, i.e. networks of simulators.

However, in order to be successful in VV&A it is fundamental to establish an effective and reliable cooperation among SME (Subject Matter Experts) covering the different simulation domains, and simulation development team in order to share knowledge and data as well as to interact during the development (Szczerbicka et al. 2000; Sarjoughian & Zeigler 2001a). In facts, it is not only necessary to have expertise in scientific and technical domain, but it results pretty important also to combine experience from operational people that served on the field and that could contribute in understanding the context and defining priorities for the different elements to models (Bruzzone et al. 2013a). In addition, a major requirement is related with the necessity to conduct joint VV&A on the whole simulator when made by different components, federates or objects; and this need to be done since the beginning of the simulation development and along its entire life cycle (Balci, 1994). This is due to the need to develop proper conceptual models (Validation) and to implement them correctly (Verification) keeping engaged the final users to generate trustiness on the Simulator (Accreditation). From this point of view data collection, knowledge acquisition and conceptual modelling are probably the key point on this process (Williams 1996; Amico, Guha, Bruzzone 2000; Zacharewicz et al. 2008).

On that regard, worth to mention is the concept of Simuland, which represents the pictures that experts have of the real system and that is used as mirror to develop the simulation conceptual model, even though sometimes not exact or complete (McLeod 1986). In facts, to complete V&V (Verification and Validation) of a model or simulator, it is required a real system as reference and the related data; however, this system is not directly measurable (e.g. because of fear present among the population), not very well known (e.g. an opponent weapon system or an emergent social behaviour) or even does not exist yet (e.g. the reliability of new doctrine). In all these cases, hypotheses should be adopted about the nature of the real system by generating an intermediate world, defined Simuland, used to create the simulation, that could introduce additional challenges (Bruzzone & Massei 2017b). Actually it is almost impossible to know exactly a real system and even SMEs have just a partial knowledge of the scenario to be simulated together without reliable data, as both comes mostly from their field experience, in the case of the military. So, it could happen that along final phases of the simulation development process, new elements arise, improving the understanding of real system and so correcting the Simuland. Overall, SMEs transfer in their observations and recommendations concerning their field experience invariably their set of belief and value judgement that can introduce a bias; on that regard, scientist have the obligation to be aware of that when they draw their conclusion and implement the model, especially when the simulated phenomena belong to social and political sciences, which are poorly understood (Hartley, 2015).

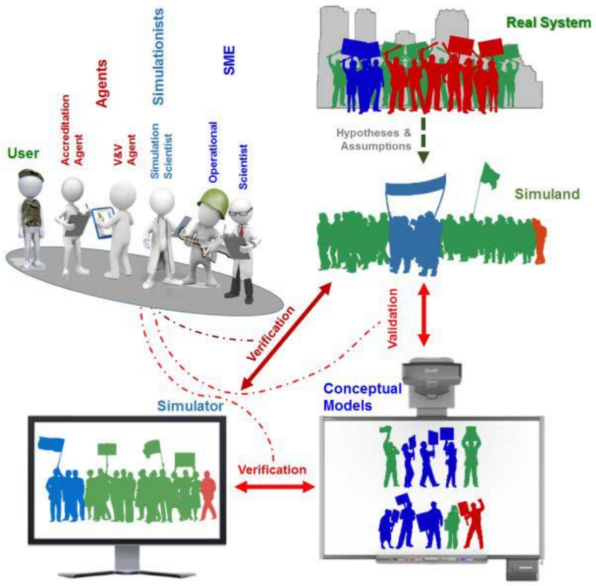


Fig. 104- System, Simuland & Model respect VV&A

All these aspects are generating a very complex context, remarkably in the case of simulation dealing with Human Behaviour, representing a major challenge, even though interesting experiences has been accumulated over the years (Cacciabue 1998; Bocca et. al. 2006; Bruzzone et al. 2011b; Di Bella 2015).

3.7.3 VV&A Methodology applied to SIMCJOH VIS & VIC

The military industry has been relying more and more on M&S, especially when it comes to training, analysis and defence acquisition; so in order to guarantee that simulators are able to reproduce adequately the real system, validation and verification process are put in place (Kim et al. 2015). VV&A methodologies and procedures are fundamental in simulation over many different areas of application including military simulators for training of cadres (Zeltzer & Pioch 1996); furthermore, examples of VV&A activities exist in the context of industrial application of HBM (Aas et al. 2009; Song & Zhang 2010). In military simulation, statistical analysis and data validation must be integrated with military strategy and military tactic analysis in VV&A (Kim et al. 2015). In other words, quantitative and qualitative analysis skills are both required; the first coming from simulation scientist, the second from experts of military operations (Di Bella, 2015).

In the proposed case study, which is SIMCJOH VIC & VIS, it was created a team composed by simulation scientists, V&V Agents, SMEs and military personnel devoted to cover the different aspects. The simulation adopted a MS2G (Modelling, interoperable Simulation and Serious Game) paradigm in order to be flexible for different use modes (Bruzzone et al. 2014a; 2014b), but in particular to support training. SIMCJOH is especially oriented to the evaluation of the impact of the decisions undertaken by the commander on human factors; in facts the human behaviour models are central in SIMCJOH VIS & VIC and proper VV&A has been required for successfully complete the project. The SIMCJOH VIS & VIC gave birth to very interesting opportunities for the application of different existing state of the art procedures and methodologies to drive the VV&A processes (Bruzzone et al.2017b). In the proposed case, the VV&A process regard HBM is complicated due to data availability and reliability, as well as to the uncertainty on human factors (Bruzzone 2014b). The V&V and Accreditation Agents have been appointed based on available resources among simulation experts, following the scheme proposed in figure below.

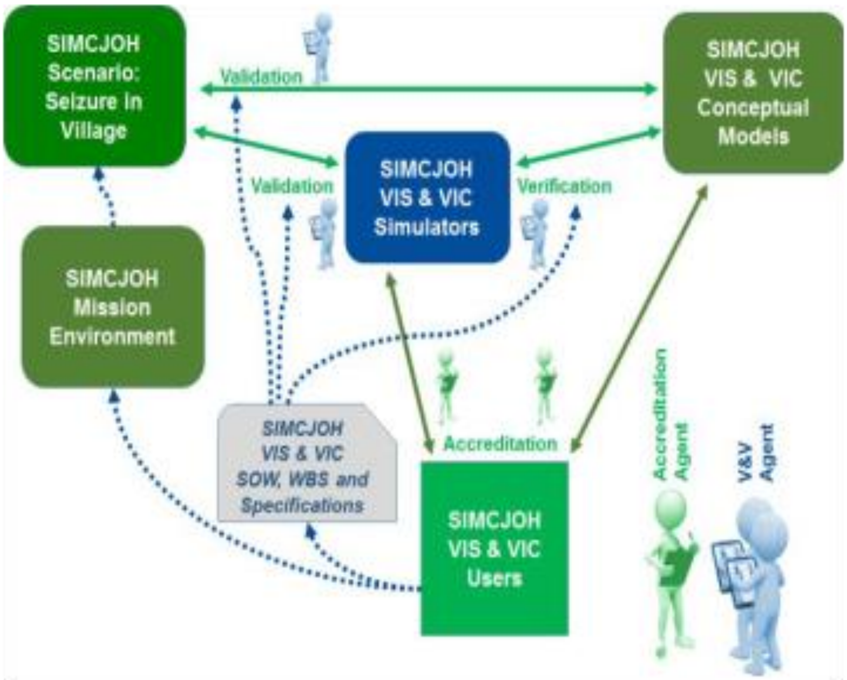


Fig. 105 - V&V and Accreditation Agents for VIS & VIC

During the early phases, it was necessary to review the Experimentation Plan for supporting VV&A and for defining:

- Mission Environment
- Terrain
- Villages
- Population Data
- Coalition Data
- OPFOR Data
- LEGAD Constraints
- Geo Political Conditions
- Planning Elements
- Tasks
- Alternative COAs
- Desired Final Effects
- MOE/MOP
- Metrics
- Exercise Plan

VV&A plan was executed by organizing meetings in order to identify errors and missed elements, as well as the testing procedures to be used on the models.
It was adopted the VV&A Plan summarized in table I below.

Table I – VV&A Plan				
ID	Title	Description	People Involved	Goal
0	**Objective Review**	Objectives and Goal review, SOW (Statement of Work) check and WBS review (Work breakdown structure) of SIMCJOH VIS & VIC Development Process	Military SME, V&V Agent, Accreditation Agents, SIMCJOH VIS & VIC Partners	To Collect Feedback about original Objectives and Goals, Simulation Specification, Use Modes and Experimentation Preferences
1	**Conceptual Model Walkthrough**	Analysis of variables, flow charts and diagrams about the models reproducing the different objects and their interactions within SIMCJOH Federation	Military SME, V&V Agent, Accreditation Agents, Scientific SME, Simulation Scientists	To review the conceptual models and human behavior models
2	**Mission Environment Review**	Analysis of Mission Environment, Background Situation and Boundary Conditions	Military SME, Selected Military Experts, Scientific SME, Simulation Scientists, SIMCJOH VIS & VIC Partners	To review the context for the experimentation of SIMCJOH VIS&VIC
3	**Scenario Review**	Review of Scenario Description and cross check with Statement of Work and potential COAs (Course of Actions)	Military SME, Selected Military Experts, Scientific SME, Simulation Scientists, , SIMCJOH VIS & VIC Partners	To review the context for the experimentation of SIMCJOH VIS&VIC and correctness check on parameters of alternative COAs
4	**Data Collection Check**	Review of the collected data, acquired knowledge and taken assumptions by SME, Check of ROE (Rules of Engagement)	Military SME, Selected Military Experts, V&V Agent, Accreditation Agents, Scientific SME, SIMCJOH VIS & VIC Partners	To Check and Certify Data, ROE, COA and assumptions to model in SIMCJOH VIS&VIC
5	**Scenario Walkthrough**	Table Top exercise with SME on the Mission Environment executing manually the scenario and verifying variables, models, factors and data	Military SME, Selected Military Experts, V&V Agent, Accreditation Agents, Scientific SME, Simulation Scientists, SIMCJOH VIS & VIC Partners	To analyze scenario consistency as well as data and model capacity to deal with the mission environments and alternative COA
6	**Implementation Checks**	GUI Review, Checks on Independent Variables, Controlled Variables, Review of the Features and functions through User Interfaces	Military SME, V&V Agent, Accreditation Agents, Simulation Scientists, SIMCJOH VIS & VIC Partners	Validate the model input and output and verify the SIMCJOH VIS & VIC Implementation
7	**Code Review and Debug**	Execution Tests, Output review, interactive debug, face validation on Virtual Environments and Synoptic Interfaces, Limit Conditions review	V&V Agent Simulation Scientists, SIMCJOH VIS & VIC Partners	Debug the Software, Test the functions and review execution of single components
8	**Single Model & Algorithm Face V&V**	Face validation on Virtual and Synoptic Interfaces by Military SME	Military SME, Technical SME, V&V Agent, Accreditation Agents, Simulation Scientists, SIMCJOH VIS & VIC Partners	Review execution of single components and models, V&V of models and algorithms
9	**Conceptual Model Validation**	Conceptual model Validation through review of Specifications, Objects and State Diagrams: review by SME	Military SME, Technical SME, V&V Agent, Accreditation Agents	To Collect Feedback about the conceptual models respect the original Objectives, Simulation Specification. To review Experimentation Preferences
10	**Integration Testing**	Testing for evaluate HLA integration and interoperability benefits	Military SME, Military Selected Personnel, SIMCJOH VIS & VIC Partners, V&V Agent, Accreditation Agents	To integrate the simulators in SIMCJOH Federation and to demonstrate interoperability benefits. Finalizing approval of experimentation proposal
11	**Preliminary Execution Testing**	Verification of SIMCJOH VIS & VIC Interfaces and Functions	Military SME, Technical SME, Simulation Scientists, Military Selected Personnel	To collect feedback and to verify SIMSJOH VIS & VIC interfaces and functions
12	**Execution Testing**	Verification of SIMCJOH VIS & VIC Features and Functions by allowing SME to make tests directly and using the simulators. Graphics analysis on Virtual and Synoptic Interfaces	Military SME, Technical SME, Military Selected Personnel, V&V Agent, Accreditation Agents	To collect feedback abput correct implementation of functions and features in SIMSJOH VIS & VIC
13	**MSpE, DOE, ANOVA**	Application of validation methodologies such as Mean Square pure error, analysis of variance and design of experiments in order to measure confidence band, experimental errors, optimal duration and optimal number of replications	SIMCJOH VIS & VIC Partners, Accreditation Agent, V&V Agent	To Measure confidence Band, experimental error, optimal duration and nymber of replications
14	**Technical Sensitivity Analysis**	Sensitivity Analysis devoted to identify the most critical factors for the mission environment and to estimate influence of different human behavior modifiers	Military & Technical SME, SIMCJOH VIS & VIC Partners, Accreditation Agent, V&V Agent	To identify the most critical variable and the influence of the human behavior modifiers on simulation Measures of Merit (MOM)
15	**Interactive Sensitivity Analysis**	Sensitivity Analysis conducted to exploit the critical factors for the mission environment and the influence of human behavior modifiers	Military SME, Technical SME, Military Selected Users, SIMCJOH VIS & VIC Partners, Accreditation Agent, V&V Agent	To accredit the Simulators and acquire user trustiness
16	**Final Interactive Experimentation**	Interactive execution and result analysis carried out on the scenario by Military SME supervised by Accreditation Agent. Graphics analysis on Virtual Environments and Synoptic Interfaces	Military SME, Technical SME, Military Selected Users, SIMCJOH VIS & VIC Partners, Accreditation Agent, V&V Agent, Simulation Scientists	To accredit the Simulators and acquire user trustiness

Table 6- SIMCJOH VV&A Plan

Finally, the scenario was finalized - the case involving a squad seizure with media implication locally and domestically, with actions affecting population. Military SMEs and Simulation Scientists played the scenario over three full days, exploring every COA and the possible implications; it emerged, that the problems experienced in addressing decision making corresponds to the real system complexity and cannot be overpassed by simulation or software solutions due to the dynamic nature of the mission environment and related data. In facts, the creation of the mission environment based on data and feedback provided by the users and the fine setting of variable lists and models carried out by VV&A pool during conceptual modelling and preliminary algorithms tests, allowed to identify the specific details for the experimentation. Concerning the VV&A of SIMCJOH VIS & VIC models, different techniques and methodologies have been used including face validation, review and walkthrough as well as dynamic techniques based on ANOVA, DOE & MSpE (Mosca et al. 1994; Montgomery 2008). In order to verify user trustiness due to current data availability and experimentation plan, it was decided to carried out a technical and an operational V&V session based on sensitivity analysis devoted to provide a more detailed analysis on the correlations and impacts of the different factors as well as on simulator effectiveness. This phase has a great impact on simulation development process and it is usually based on reviewing documents with SMEs and to correlated them with original requirements, for instance if the case was carried out respect the original SIMCJOH VIS & VIC Simulator description. The definition of measures related to the human factors to be used for testing and experimentation resulted critical to finalize the experimental plan. For instance, it was decided to define key performance indexes including among the others: fear and aggressiveness level on the population, size of the demonstration, perception of deterrence by different parties, local and domestic media perception; some of these factors are real and measurable (e.g. number of people participating at the demonstration), others are just virtual, therefore their evolution along time and in relation with key events support the VV&A of the Simulators.

A conceptual model walkthrough has been executed; such informal technique allows to review the proposed models to be used and implemented in the simulator by interacting with the SME. Considering the subject of HBM, this requires to adopt representations that should be easily implemented, but also intuitive for being accessible to psychology, sociology and military SME. In our case Flow diagrams have been extensively used as proposed in figure below.

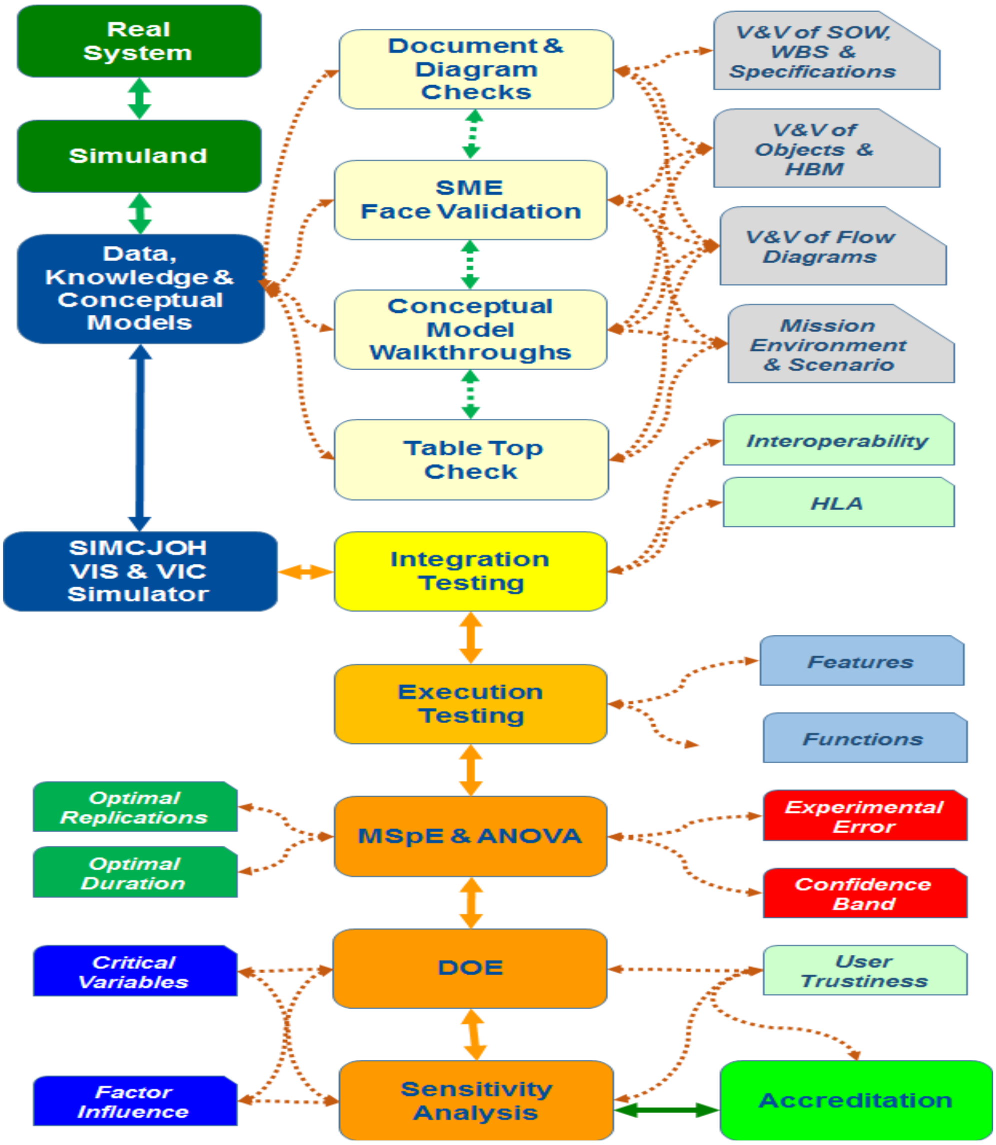


Fig.106- VV&A Methodologies & Techniques

As anticipated, the definition of Mission Environment and Scenario is fundamental and does not represent a limitation for the models and the simulators; vice versa the proper definition of these elements and related boundaries allows to conduct a reliable experimentation that could replicated with measurable Measures of Merits that allow to finalize VV&A in this framework considering the needs of Strategic Decision Makers.

Data Collection Check was very critical, because in terms of population and related parameters, usually the information is pretty inhomogeneous and not aligned in terms of validity time and area. In addition, confidential aspects and classification could introduce further challenges. Due to these reasons, it was decided to use just public domain data and it resulted critical to engage in the process the people actually in service in planning operations in the area; in this way it was possible to fine tune such data in consistency with realistic situations without using any sensible information.

The use of SMEs allowed to execute the scenario before finalize the simulation development, in order to check conceptual interoperability among models and consistency among data and parameters.

The techniques summarized in the table allowed to finalize technical aspects like Implementation Checks, Code Review and Debug, Single Model & Algorithm Face V&V and to arrive to an execution capability able to deal with SME face validation. Obviously the single model/algorithm V&V does not guarantee the simulation validity, therefore it is a useful corner stone to check proper implementation and remove doubts about some single elements before moving to integration testing and overall execution. In this phase the use of Animation, Virtual Reality and Dynamic Synoptic Representations is very important to be able to complete V&V of complex phenomena; SIMCJOH VIS for example, proposes a graphic representation (see figure below) including the human behaviour levels (e.g. fear, fatigue, aggressiveness, stress, deterrence perception, media attitudes), change speeds & accelerations, history as well as the factors contributing to their evolution.

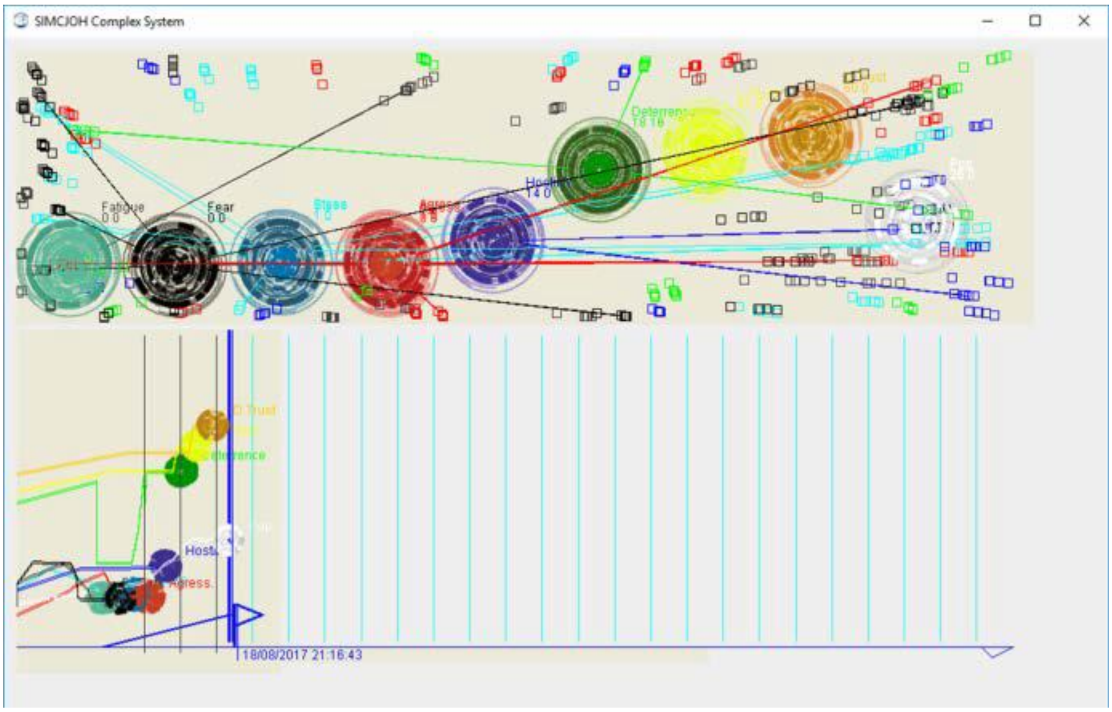


Fig. 107– GUI for HBM Temporal & Dynamic Evolution

The Conceptual Model Validation represents a landmark in VV&A, allowing to check conceptual model development versus original requirements, considering data collected and knowledge acquired along development life cycle; these aspects turn even more mature as soon as single model tests allows to select the most promising solutions to implement the simulation.

For what concern MSpE, DOE, ANOVA, such dynamic quantitative methodologies are fundamental to estimate experimental error and confidence bands considering the highly stochastic nature of the HBM; in this phase VV&A agents are involved on a technical basis, preparing all documentation required for the forthcoming accreditation procedures.

The final step was devoted to finalize simulator accreditation by users and military experts, by distributing and analysing the experimental analysis results during an experimentation carried out directly by them. In SIMCJOH VIS & VIC the test took a whole day, and was repeated other times to engage other military subjects, resulting successful. SIMCJOH VIS &VIC Verification and Validation process passed with success the face validation of Models and GUI, and the project moved forward for the dynamic testing during the experimentation. The integration test on HLA models was successful passed; the functional tests as well as final experimentation resulted pretty satisfactory receiving very positive feedbacks from military SMEs. It is important to outline that the verification and validation based on experimental analysis was fundamental to create trustiness in the HBM embedded in SIMCJOH VIS & VIC. In facts the success of this aspects supported the fully achievement also of the whole SIMCJOH Project and its objectives.

In conclusion, the VV&A methodology followed for the development of SIMCJOH adhered to the principles of:

- reducing risks derived from poor decisions based on incorrect model and simulations (Kilikauskas & David, 2005);
- reduce the probability that inappropriate application of M&S results for the specific intended use will produce unacceptable consequences to the decision maker (Youngblood et al. 2000; 2018).

CONCLUSIONS

Hybrid is not the New War. What it is new in warfare has been brought by globalization paired with the transition to the information age and rising geopolitical tensions, which have put new emphasis on hostilities that manifest themselves in a way that it is named “hybrid”. The seed of hybridization of conflicts, planted in 1999, germinated almost 20 years later; in such contest, conflicts are less and less driven by military means, so the comprehension of DIMEFIL & PMESII_PT dimensions are necessary in order to understand and subsequently model Hybrid Warfare.

Hybrid Warfare is a deliberate choice of an aggressor. While militarily weak nations can resort to it in order to re-balance the odds, instead military strong nations appreciate its inherent effectiveness coupled with the denial of direct responsibility, thus circumventing the rules of the International Community (IC). From this point of view, the delivery of a considerable amount of damage across the DIMEFIL vectors against the opponent, could be viewed indeed by an aggressor as a fascinating opportunity. In order to be successful, Hybrid Warfare should consist of a highly coordinated, sapient mix of diverse and dynamic combination of regular forces, irregular forces (even criminal elements), cyber disruption etc., in order to achieve the desired effects against the entire PMESII_PT status of the opponent.

However, the owner of the strategy, i.e. the aggressor, by keeping the threshold of impunity as high as possible and managing to decrease the willingness of the defender, can maintain his Hybrid Warfare at a diplomatically feasible level; so the model of the capacity, willingness and threshold, as proposed by Cayirci, Bruzzone, Longo and Gunneriusson (2016), remains critical to comprehend Hybrid Warfare. Its dynamicity is able to capture the evanescent, blurring line between Hybrid Warfare and Conventional Warfare. In such contest time is the critical factor: this because it is hard to foreseen for the aggressor how long he can keep up with such strategy without risking either the retaliation from the International Community or the depletion of resources across its own DIMEFIL/PMESII_PT spectrum. Similar discourse affects the defender: if he isn’t able to cope with Hybrid Threats (i.e. taking no action), time works against him; if he is, he can start to develop counter narrative and address physical countermeasures. However, this can lead, in the medium long period, to an unforeseen (both for the attacker and the defender) escalation into a large, conventional, armed conflict.

Examining the same phenomena, Balaban & Mielniczek (2018) developed a conceptual model for Hybrid Threats/Conflict/Warfare, which has the merit that it explains very clearly, by means of a Causal Loop Diagram, how Hybrid Warfare accumulates into a Hybrid conflict and how such conflict can reach the intensity of a Hybrid war; in their analysis, the strictness of law (whose content and meaning it is however subjected to a highly political controversial and divisive debate over the IC, as well as scrutiny of the public opinion within the single nations) defines the line between the Hybrid Conflict and Hybrid War.

Throughout History, especially the most recent one, war and military operations have been rarely (almost never) purely kinetic. The performance of operations that required more than kinetic effects drove the development of DIMEFIL/PMESII_PT models and in turn this drive the development of Human Social Culture Behavior Modelling (HCSB), which should stand at the core of the Hybrid Warfare modelling and simulation efforts. Elaborating on this perspective, the ET 43 conducted a survey of the current M&S tools available and meaningful toward Hybrid Warfare modelling. Even though the survey identified several gaps to be covered and the necessity of further inquiries, the outcome has been that multi-agent simulations are relevant in designing, analyzing and evaluating complex socio natural systems such as civil wars, political instability, economic development. From the survey emerged as well that the most innovative researches within modelling and simulation community could be strategic for addressing almost all the areas of different layers of Hybrid Warfare. Multi Layers models are fundamental to evaluate Strategies and Support Decisions: currently there are favorable conditions to implement models of Hybrid Warfare, such as CAPRICORN, DIES IRAE, SIMCJOH and TREX, in order to further develop tools and war-games for studying new tactics, execute collective training and to support decisions making and analysis planning. The proposed approach is based on the idea to create a mosaic made by HLA interoperable simulators able to be combined as tiles to cover an extensive part of the Hybrid Warfare, giving the users an interactive and intuitive environment based on the “Modelling interoperable Simulation and Serious Game” (MS2G) approach. From this point of view, the impressive capabilities achieved by IA-CGF in human behavior modeling to

support population simulation as well as their native HLA structure, suggests to adopt them as core engine in this application field.
However, it necessary to highlight that, when modelling DIMEFIL/PMESII_PT domains, the researcher has to be aware of the bias introduced by the fact that especially Political and Social “science” are mostly accompanied and built around value judgement. From this perspective, the models proposed by Cayirci, Bruzzone, Guinnarson (2016) and by Balaban & Mileniczek (2018) are indeed a courageous tentative to import, into the domain of particularly poorly understood phenomena (social, politics, and to a lesser degree economics - Hartley, 2016), the mathematical and statistical instruments and the methodologies employed by the pure, hard sciences. Nevertheless, just using the instruments and the methodology of the hard sciences it is not enough to obtain the objectivity, and is such aspect the representations of Hybrid Warfare mechanics could meet their limit: this is posed by the fact that they use, as input for the equations that represents Hybrid Warfare, not physical data observed during a scientific experiment, but rather observation of the reality that assumes implicitly and explicitly a value judgment, which *could* lead to a biased output. Such value judgement it is subjective, and not objective like the mathematical and physical sciences; when this is not well understood and managed by the academic and the researcher, it can introduce distortions - which are unacceptable for the purpose of the Science - which could be used as well to enforce a narrative mainstream that contains a so called “truth”, which lies inside the boundary of politics rather than Science.
Those observations around subjectivity of social sciences vs objectivity of pure sciences, being nothing new, suggest however the need to examine the problem under a new perspective, less philosophical and more leaned toward the practical application. The suggestion that the author want make here is that the Verification and Validation process, in particular the methodology used by Professor Bruzzone in doing V&V for SIMCJOH (2015) and the one described in the Modelling & Simulation User Risk Methodology (MURM) developed by Youngblood et al. (2018), could be applied to evaluate if there is a bias and the extent of the it, or at least making clear the value judgment adopted in developing the DIMEFIL/PMESII_PT models. Such V&V research is however outside the scope of the present work, even though it is an offspring of it, and for such reason the author would like to make further inquiries on this particular subject in the future.

Then, the theoretical discourse around Hybrid Warfare has been completed addressing the need to establish a new discipline, Strategic Engineering, very much necessary especially now, because of the current a political and economic environment which allocates diminishing resources to Defense and Homeland Security (at least in Europe). Hybrid Warfare and Strategic Engineering are two flip of the same coin: complexity brought by the former can be dealt with the knowledge and tools gained from the latter. For this reason, Strategic Engineering can successfully address challenges, especially when coupled with the understanding and the management of the fourth dimension of military and hybrid operations, time. As elaborated by Leonhard and extensively discussed in the present work, addressing the concern posed by time is necessary for the success of any military or Hybrid confrontation.

The SIMCJOH project, examined under the above perspective, proved that the simulator has the ability to address the fourth dimension of military and non-military confrontation. In operations, time is the most critical factor during execution, and this was successfully transferred inside the simulator; as such, SIMCJOH in its HLA federation mode can be viewed as a training tool and as well a dynamic generator of events for the MEL/MIL execution during any CAX exercise. In conclusion, SIMCJOH project successfully faces new challenging aspects respect human behavior modelling, by developing new simulation models able to support Commanders and their Staff for training or decision making.

Finally, the question posed by Leonhard in terms of recognition of the importance of time management of military operations - nowadays Hybrid Conflict - has not been answered yet; however, the author believes that Modelling and Simulation tools and techniques can represent the safe “recipient” where innovative scientific solutions can be tested, exploiting the advantage of doing it in a synthetic, safe environment.

APPENDIX 1
M&S tools relevant for Hybrid Warfare Modelling (Geller, 2016)

Name	*Type*	*Topics*
RTE	Multi Agent Network Model of State Failure	• State Failure • Lack of State Legitimacy • Province Secession • Hostility Tension • Corruption • Intergroup Conflicts • Link Terrorists and Weak States • Corruption • Cost Benefit Analysis • Real World Data Terrorist Level • Criminal Level • Foreign Military Aid Level • Lack of Services • Indonesia & Thailand case studies
Senturion	Game Theory Model	• Game Theory based platform on Adversarial and Competitive Interaction • Spatial Bargaining • Political Process
PS-I Modelling Platform	Model of Artificial State Analysing Secession and Secessionist Pattern, through Constructivist Identity Theory	• Multicultural Features • Multi-ethnic Features • Social and Human Model • Constructivist Identity Theory • Social Alienation • Regional Concentration • Quebec Corse and Kashmir Example

AfriLand	Model of a region with Ten Neighbouring Polities	• Sociocultural and Environmental Dynamic Analysis • Local HADR Scenario • East Africa Scenario • Connected to RebeLand
RebeLand	Island Polity Model	• Socio-political Models • HADR • Local HADR Scenario • East Africa Scenario • Connected to AfriLand
FactionSim	Serious Game, Cultural Training	• Generic Game Simulation for Social Science and Policymaker • South Asia, Middle East, Horn of Africa Scenario • Cognitive, Social and Economic Models • Connected to NonKeen Vilage
NonKeen Village	Serious Game, Cultural Training	• Generic Game Simulation for Social Science and Policymaker • South Asia, Middle East, Horn of Africa Scenario Cognitive • Social and Economic Models • Connected to FactionSim
OOTW Toolbox	Toolbox for Training	• Set of models and simulators such as: JCATS, Pythagoras, UOB DAT, XMT, Canadian Forces Landmine Dbase, XML Files
EINstein	Multi Agent Modelling, Genetic Algorithm, Combat Simulation	• Combat Simulation • Land Combat Pattern

Pashtun tribal system	Multi Agent Model	• Opium Supply Chain Emergent Behaviour • Jirga Pashtun Scenarios • Human Behaviour Model • Tribal Society Model, • Scenarios in South Waziristan, Afghanistan
A model of the political economy of Afghanistan, Social Behaviour Model of a Specific Area	Multi-agent Model of Political Economy	• Afghanistan Political Economy Model • Country scale • Heterogeneous Population • Country-Scale Drug Process and Economy Simulation • Household-Resolution Multi-Agent Simulation • Rural Population Model • Afghanistan Scenario
CLARION	Simulation Model for Campaign Planning and Analysis	• Object Oriented C++ Simulation • Air Campaign Model • Land Combat Model • Cognitive Model
Diamond	High-Level Multi-Party Simulation Model for Analysing Peace Support Operations,	• Object Oriented C++ Simulation • Peacekeeping and Peace Enforcement Model • Tactical Scale Agents non-interactive simulation • Diplomat and military components in non-warfighting • Bosnia, Mozambic and Sierra Leone scenario
PSOM	Multiple Party Military Forces	• GO & NGO entities • Iraq post-war scenario

StratMas	Interacting War gaming Scenario	• Game Environment for Command and Control Operation • Population Dynamics • Post-Conflict Reconstruction Afghanistan Scenario, Future Iraq Scenario
PAX	Multi Agent Model	• Civilian Behaviour model • Psychological Driver Model • Peace keeping Operation Strategies • 3D extension for Scenario Replay.
Attitude Change and Diffusion	Research Project and Models	• Model of Attitude and Opinion Diffusion in the Population • Social Judgement Theory • Attitude Change Model • Assimilation Effect
Humanitarian Assistance and Disaster Relief Model	Multi Agent Model	• HADR Planning • Short Term Planning • Humanitarian Assistance Process
CORMAS	Different Models of Biological Climate and Hydrological Interdependency	• Different Parties Simulation • Integrated Natural Resources Management in Developing country and Context • Village Level Simulation • Thai and Vietnamese Scenario • Senegal and Easter Cameroun Scenario • Drug & Crime in Melbourne Scenario • Irrigation and Water Sharing
PIOVRA	Intelligent Agent & High Level Architecture Simulation	• Poly-functional Intelligent Operational Virtual Reality Agents • Federated in HLA with JTLS and IA-CGF • Intelligent Agents • Human Behaviour Modelling • Civil Disorders Simulation • Multiple Ethnic Group

		• Domestic Riots and Middle East Disorder Scenario
POWERS	Stochastic Simulation and Intelligent Agents	• Psychological Operations and Weapons: Evaluation by Robust Simulation • Human Behaviour Models • PSYOPS
TRAMAS Katrina Like	Discrete Event Stochastic Simulator	• Transportation Management & Simulation Katrina Like Crisis Simulation • An Entire State Simulation: Transportation Layer • Respect of Public Directive based on Human Behaviour Models • State Disaster Simulation • Katrina Hurricane Scenario
MOSCA	Stochastic Simulation and Intelligent Agents	• Modelling Supply Chain Attack • Food Contamination and Population Fear • Fear and Saturation Dynamics • Media Countermeasure Effectiveness
Pandora	Stochastic Simulation and Intelligent Agents	• Pandemic Dynamic Objects Reactive Agents • Pandemics Dynamics • Human Behaviour Model of Population • Quarantine Directive and HBM • H1N1 Australia Scenario
RATS	Stochastic Simulation and Intelligent Agents	• Riots • Agitators & Terrorists • Warlord Models • Human Behaviour Model

IA-CGF	High Level Architecture Intelligent Agents	• Intelligent Agents Computer Generated Forces • Interoperable HLA Simulation • Psychological and Sociological Models • Multiresolution from Individuals to Interest Groups • Human Behaviour Modelling • Population Simulation • Entity Modules, Human Modifiers & NCF (Non- Conventional Frameworks) for specific Scenarios • Multiple Scenario in Asia, Europe & Africa
CAPRICORN	High Level Architecture Intelligent Agents	• CIMIC And Planning Research In Complex Operational Realistic Network • CIMIC Models • PSYOPS Models • Human Behaviour Models • Environmental Conditions Models • Population Modelling • Individual and People Models • Interest Group Models • HLA Native Simulation • CAPRICORN Federation • Kapisa Afghanistan Scenario
PANOPEA	Intelligent Agents & Stochastic Simulation	• IA-CGF Intelligent Agent, HLA Simulation • C2 Agility Model • Multiple Actors (e.g. NATO, EU, ВМФ России, Local Coast Guards, etc.) • Maritime Interdiction and Social Context • Cyber Defence Model • Aden Gulf Simulation

IA-CGF and Haiti Case	High Level Architecture Intelligent Agents	• IA-CGF Intelligent Agent, HLA Simulation • Simulation of Earthquake (2010 Haiti scenario) • Psychological and Social Models • Food, Water and Health Care Needs • Simulation over 1 million inhabitant town
IA-CGF NCF Riots & IA-CGF NCF EQ	High Level Architecture Intelligent Agents	• IA-CGF Intelligent Agent, HLA Simulation • Looting in Urban Environments • Riots and Civil Disorders • Human Behaviour Models
PSYSOP	High Level Architecture Intelligent Agents	• Psychological and cultural Simulation of Population • IA-CGF Intelligent Agent, HLA Simulation • Population modelling for Villages, Towns and Provinces
CGF C4 IT	High Level Architecture Simulation, Intelligent Agents, C2 Simulation	• Computer Generated Forces & C4 for Italian Army • IA-CGF Intelligent Agent, HLA Simulation • Human Behaviour Modifiers • Asymmetric Warfare • NATO Net-centric Multi Level Maturity C2 • Population Generation and Simulation • Village Simulation • Multiplayer Simulation (ANA, ANP, Coalition, Insurgent) • HLA Federation with IA-CGF NCGs and SC Communication Simulator in

		OPNET™ • Zabul Province and Afghanistan Scenario
DYTACCO	Modeling, Interoperable Simulation and Serious Game	• Dynamic Targeting Collateral Damages and Consequences • Joint Fire and Intelligence Branch (JFIB) • IA-CGF Intelligent Agent, HLA Simulation • Collateral Damages and Seconds Effects on Population
IA-CGF UCOIN	Stochastic Simulation and Intelligent Agents	• Intelligence Agent Computer Generated Forces UAV and Counter-Insurgency • IA-CGF Intelligent Agent • COIN Models • Desert Area and Village Simulation • Saharan Area Scenario
SIMCJOH	Modeling, Interoperable Simulation and Serious Game	• Simulation of Multi Coalition Joint Operations involving Human Modelling - Virtual Interoperable Simulation & Virtual Interoperable Commander • IA-CGF Intelligent Agent, HLA Simulation • Human Behaviour Modelling and Multi Coalition Model in Virtual Interoperable Simulator (SIMCJOH VIS) • VIC Serious Games federated with Simulator • Communication Models in Simulation of Communication (SC) and Scenario Generator and Animator (SGA) • Entity Level Simulation in GESI • HLA Federation • Lebanon Scenario

T-REX	Modeling, Interoperable Simulation and Serious Game	• Threat network simulation for REactive eXperience • IA-CGF Intelligent Agent, HLA Simulation • Simulation of Town and Villages • Human Behaviour Models • Cyberspace Simulation • Critical Infrastructure and Commodity Layers Simulation (e.g. Water, Power) • Thread Network and Asymmetric Warfare • Hybrid Actions and Event • Tested on Desert District Scenario
JESSI	Modeling, Interoperable Simulation and Serious Game	• Joint Environment for Serious Games Simulation and Interoperability • IA-CGF Intelligent Agent, HLA Simulation • Simulation of Autonomous Systems and Traditional Asset • Cyberspace Simulation
IDRASS	Modeling, Interoperable Simulation and Serious Game	• Immersive Disaster Relief and Autonomous System Simulation • IA-CGF Intelligent Agent, HLA Simulation • Simulation of Accidents Nuclear Plant and Chemical Facility • CBRN • Ukraine Scenario
MOSES	Stochastic Simulation	• Modelling Sustainable Environments through Simulation • Stochastic Simulation • Environmental Models • Urban Development Model • Population Model

		• Coastal Scenarios
SPIDER	Interoperable and Immersive CAVE	• Simulation Practical Immersive Dynamic Environment for Reengineering • Interactive Common Environment to Supervise Complex Simulation • Interoperable HLA Simulation • Cooperative Environment
DIES IRAE	Intelligent Agent Interoperable Simulation	• Incidents & Emergencies Simulation Interoperable Relief Advanced Evaluator • IA-CGF Intelligent Agent, HLA Simulation • Logistics and Transportation Models • Population Models • Human Behaviour Models • HADR Models • South Sudan Scenario
CMHE	Conceptual Model for Hybrid Environments	• Conceptual Model • Montecarlo Techniques • Capacity, Willingness, Threshold in Hybrid Warfare • Religious and Ethnical Country Divisions • Hybrid Events

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