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INTEROPERABILITY FOR MODELING AND SIMULATION IN MARITIME EXTENDED FRAMEWORK

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INTEROPERABILITY FOR MODELING AND SIMULATION IN MARITIME EXTENDED FRAMEWORK

Abstract

This thesis reports on the most relevant researches performed during the years of the Ph.D. at the Genova University and within the Simulation Team. The researches have been performed according to M&S well known recognized standards. The studies performed on interoperable simulation cover all the environments of the Extended Maritime Framework, namely Sea Surface, Underwater, Air, Coast & Land, Space and Cyber Space. The applications cover both the civil and defence domain. The aim is to demonstrate the potential of M&S applications for the Extended Maritime Framework, applied to innovative unmanned vehicles as well as to traditional assets, human personnel included. A variety of techniques and methodology have been fruitfully applied in the researches, ranging from interoperable simulation, discrete event simulation, stochastic simulation, artificial intelligence, decision support system and even human behaviour modelling.

Glossary

AADSS	Asset Allocator Decision Support System
AI	Artificial Intelligence
ANN	Artificial Neural Network
ANOVA	Analysis of Variance
AODCS	Attitude and Orbit Determination and Control System model
APSU	Automatic Proactive Simulator for Unified track generation
AR	Augmented Reality
ARTEM	Augmented Reality TErrain interoperable Module
AUV	Autonomous Underwater Vehicles
CAVE	Cave Automatic Virtual Environment
CAX	Computer Assisted Exercise
CBRN	Chemical, Biological, Radiological and Nuclear
CDM	Crisis Disaster Management
CIMIC	Civil Military Cooperation
COA	Course of Action
CONOPS	Concept of Operations
COP	Cooperative behaviour
COP	Common Operational Picture
C2	Command and Control
DARPA	Defence Advanced Research Projects Agency

DSEEP	Distributed Simulation Engineering and Execution Process
DSS	Decision Support Systems
DSS	Decision Support Systems
EC	European Commission
EMF	Extended Maritime Framework
FASOLT	Foremost Autonomous Solutions for Operations in industriaL plant
FCS	Future Combat Systems
FEDEP	Federation Development Process
FEM	Finite Element Modeling
FOE	Aggressive behaviour
FOM	Federation Object Model
GBM	Glioblastoma Multiforme
GUI	Graphical User Interface
HBM	Human behaviour modifiers
HIL	Hardware in the Loop
HIL/SIL	Hardware and Software in the Loop
HLA	High Level Architecture
HMI	Human Machine Interactions
HMI	Human Machine Interface
IA-CGF	Intelligent Agent Computer Generated Forces
ICT	Information Communication Technology

IDRASS	Immersive Disaster Relief and Autonomous System Simulation
IED	Improvised Explosive Device
IEEE	Institute of Electrical and Electronics Engineers
IPHITOS	Interoperable simulation of a Protection solution based on light Interceptor Tackler operating in Outer Space
JAMS2	Joint Advanced Marine Security Simulator
JESSI	Joint Environment for Serious Games, Simulation and Interoperability
JSON	JavaScript Object Notation
KPI	Key Performance Indicator
LoA	Level of Autonomy
LOS	Line of Sight
LVC	Live-Virtual-Constructive
M&S	Modelling and Simulation
M&T	Maintenance and Training
MALICIA	Model of Advanced pLanner for Interoperable Computer Interactive simulation
MDCS	Multi-Domain Control Station
MDTB	Multi-Domain Test Bed
MEL/MIL	Main Event List/Main Incident List
MMI	Marina Militare Italiana
MMI	Machine-Machine Interaction

MOE	Measure of Effectiveness
MOM	Measures of Merit
MOSES	Modelling Sustainable Environments through Simulation
MOOS	Mission Oriented Operating Suite
MOP	Measure of Performances
MPA	Maritime Patrolling Aircraft
MRS	Multi Robot Systems
MS2G	Modelling and interoperable Simulation Serious Game
MSpE	Mean Square Pure Error
NATO	North Atlantic Treaty Organization
NCF	Non Conventional Framework
NCP	Non-cooperative behaviour
NGO	Non-governmental organization
NRE	Non-reactive behaviour
OBSW	On Board Software for Power Systems model
ONR	Office of Naval Research
ORBAT	Order of battle
PS	Power Systems model
RANS	Reynolds-averaged Navier Stokes
REG	Regular behaviour
RHIB	Rigid Hull Inflatable Boat

ROE	Rules of Engagement
ROS	Robot Operating System
ROV	Remotely Operated Vehicle
RPM	Recognized Maritime Picture
RTI	Run Time Infrastructure
SCG	Scaled Conjugate Gradient
SIL	Software In the Loop
SISMA	Medical Simulator of Astronaut including treatments, analysis and sickness models
SISO	Simulation Interoperability Standards Organization
SLAMS	Simultaneous Localization & Mapping
SME	Subject Matter Experts
SO2UCI	Simulation for Off Shore, On Shore & Underwater Critical Infrastructure
SPIDER	Simulation Practical Immersive Dynamic Environment for Reengineering
SPIRALS	Space Interoperable Refilling and Advanced Logistics Simulator
SSC Pacific	Space and Naval Warfare Systems Centre Pacific
ST_CIPROS	Simulation Team Civil PROtection Simulator
ST_CRISOM	Simulation Team Crisis Simulation, Organization and Management
STANAG	NATO Standards
TT&CS	Telemetry, Tracking and Communications System
UAS	Unmanned Autonomous Systems

UAV	Unmanned Aerial Vehicles
UGV	Unmanned Ground Vehicle
UMS	Unmanned Maritime Systems
US DoD	United States Department of Defence
USV	Unmanned Surface Vehicles
UxV	Unmanned multi-domain Vehicles
VAED	Virtual Aided Engineering & Design
VV&A	Verification, Validation and Accreditation
WP	Work Package

Indice

Introduction

This thesis proposes an innovative common environment for maritime Modeling and Simulation (M&S) with the intent to support and guide the engineering processes by adoption of marine interoperable simulators.

The thesis reports on the adoption of architectures for developing simulators able to be federated by using HLA Standard (IEEE 1516 evolved) in order to address the multi domain marine context here defined as Extended Maritime Framework (EMF). Hereafter is highlighted the architecture and the modelling approach to be followed to guarantee modularity, easy development and the capability to be integrated in the EMF scenario for Joint Naval Operations; the research provides also guidelines for experimentation and Verification, Validation and Accreditation (VV&A). Furthermore the proposed architecture and modelling guidelines identify the different modular components addressing each subject/entity by defining the required objects, attributes and interactions.

By this approach the simulators of the different assets and parties could be easily integrated in this EMF Federation. In particular the thesis focuses on federations for the development of new marine persistent and flexible capabilities based on innovative autonomous systems operating within the EMF; in this document the author reports on the researches performed during the Ph.D. related to the use of federations for testing and experimenting on new Autonomous Underwater Vehicles (AUV) integrated with traditional assets.

Marine domain is a strategic resource for world evolution, most of world population is leaving over the coastlines and the large majority of goods are shipped; in addition, oceans are holding crucial resources for human activities from energy (e.g. oil rigs, underwater pipelines) to food (e.g. fishing); ports represents very important nodes for Nations and maritime trading lines are critical for guaranteeing development. Due to these reasons protection and control of sea is a strategic issue.

Today, the dimensions affecting the oceans are extended over several domains; the author is adopting the definition of Extended Maritime Framework (EMF) as combination of: Sea Surface, Underwater, Air, Coast & Land, Space and Cyber Space; almost all activities in the marine context are interacting with entities and resources located evenly over these domains: for instance a ship is communicating through satellites, accessing web resources, interacting with coastal ports during loading/unloading operations.

This context is defined EMF and represents the mission environment to be investigated in order to develop innovative solutions. The author is currently involved in projects related to Researches in civil and defence applications within this context so it is evident the opportunity to create a simulation environment able to support investigations and virtual experimentation in EMF.

In addition, today the introduction of autonomous new systems introduces the necessity to evaluate new configurations and operational models to utilize these entities (e.g. Autonomous Underwater Vehicles or Unmanned Surface Vehicles) guaranteeing collaboration and synergy and distributing tasks and workload in the most efficient way.

Use of autonomous systems in collaborative modes as well as in competitive scenario represents a very challenging context, especially in EMF, due to the high influence of the different domains on the capabilities of the different vehicles and platforms.

Due to these reasons it is evident the necessity to create a simulation framework to study this context; indeed, the EMF represent a very good framework for general purpose use of new technologies that could be readapted to address defence and littoral protection as well as to support oil & gas or shipping operations.

In general, the resources interoperating over EMF represent a heterogeneous network, therefore communications as well as sensor performance are highly affected by the different domains.

Therefore, the complexity of the context as well as the high number of complex interactions among the entities does not allow approaching the problem with traditional methodologies; due to these reasons the author have been requested to develop and interoperable simulation architecture devoted to be used as a test bed for new systems operating in the EMF.

Modeling and Simulation (M&S) allows conducting experimental analysis over complex systems where different elements are dynamically interacting; in particular M&S provide a cost-effective test bed and verification tool reducing potential failures in real trials. Its applicability to Hardware and Software in the loop helps engineers in finding errors in the system embedded software and to have better insights in operation and dynamics (Montelo & Furukawa 2010).

The goal of Modeling and Simulation (M&S) within this project is to provide both test-bed capabilities at mission level to support and analyse performances of unmanned system accomplishing tasks integrated in a traditional asset, and at physical level to provide support for virtual prototyping.

Furthermore, existing standards related to this topic have been studied to contribute to their evolution and eventually to develop new ones aiming to ensure future systems to born interoperable.

A preliminary test-bed design is developed simulating a multiple vehicle scenario. In this first simulator interoperability will be augmented to connect simulator with middleware such as ROS and MOOS, and to connect to Hardware in the Loop (HIL).

It has to be said that Unmanned Maritime Systems (UMS) are still a relatively immature technology, thus the development of a Multi-Domain Test Bed (MDTB) and a Multi-Domain Control Station (MDCS) provide the capability to carry realistic and extensive simulations.

The proposed simulation will be based on the High Level Architecture (HLA) approach standardized as the IEEE 1516-series after being addressed by NATO M&S Master plan (NATO M&S Master Plan); this standard architecture has been developed to provide a flexible approach to support interoperability and distributed modelling and simulation. The HLA defines an integrated approach providing a common framework for the interconnection of interacting simulations. HLA has been developed by the Simulation Interoperability Standards Organization (SISO) and published by IEEE. To date it is a prescribed or recommended standard used by NATO as well as national department of defence. Its

structure allows tools provided by different suppliers to become interoperable, thus reducing cost, time and risk for end users.

Traditionally HLA has been developed for defence applications, for instance to train different pilots skills in flight simulators or at Command and Control (C2) level to train officers ability to take decisions. Nowadays its applicability spans from space missions, where emergency situation can be trained without risks, to joint operation between police, fire fighters, Red Cross, from Air Traffic Management, to off-shore oil production and so forth.

As a matter of technical description of the intended architecture to use, HLA topology is a Service Bus. Each system, so called Federate, has one connection to the service bus, called Run Time Infrastructure (RTI) providing information, synchronization, and coordination services. A common set of services is agreed in the Federation Object Model (FOM) containing descriptions of the information exchanged in the federation. Each federates provide-publish or consume-subscribe the particular service that it is interested in through the RTI (Moller 2006).

In HLA context, federated simulators interoperate between each other through RTI publishing/subscribing objects or objects attributes, and interaction between objects published in the current simulation. When an object is published in the federation that specific object starts to exist for other federated simulator and thus can interact with other instances generated in the simulation.

One of the main goal of HLA is to standardize techniques for time management among heterogeneous simulators and systems included in the federation. The adoption of HLA Standard guarantees the possibility to operate both in fast time and real time; models have then to be time constrained and time regulating. This is pursued in order to run long simulations in fast time, for instance to train capability assessment, and to operate in real time to involve real hardware in the simulation ensuring proper hardware performances.

A valid example of how much simulation has gained his role in engineering processes in maritime related fields is the use of simulation tools to analyse the structural behaviour such as Finite Element Modeling (FEM) codes or the fluid dynamic behaviour with Reynolds Averaged Navier Stokes (RANS), Potential Method, Panel methods, Turbulence models codes, and so forth. Such tools are nowadays widely used and would be unthinkable to carry out a brand new design without them.

Other different types of simulators are used as virtual prototypes offering the opportunity to crosscheck the design versus performance before building expensive physical prototypes.

The use of interoperable simulators allows developing a simulator for each single relevant actor in the play making requirements checking more direct and addressable. As a matter of example, in an extended maritime framework (EMF) each vehicle may be a single simulator; at the same time vehicles can be made out of single simulators constituting a system.

This approach suits different applications even if this research focuses especially on virtual prototyping by building up an interoperable simulation using dynamic models of the controls, sensors, physics and communications.

The final goal of this simulation environment is currently to support the engineering of new capabilities in the EMF based on collaborative use of autonomous systems.

The proposed federations are thus suitable for other kind of applications including: training, education, capability assessment, operational support, tactical decision aid, mission rehearsal, etc.; models with different resolutions can be integrated in this architecture to address different applicative contexts along the life cycle of the new solution; for instance it is possible to support Measures of Merit (MOM), Measure of Performances (MOP) and Measure of Effectiveness (MOE) in evaluating a specific mission environments respect alternative Concept of Operations (CONOPS) or technological solutions;

Simulations in EMF takes place in scenarios made by the six spaces listed below:

1. Underwater
2. Surface (Including maritime traffic simulation)
3. Air (assets supporting land and surface operations)
4. Land/Coast (harbours and infrastructures)
5. Cyber space (the presence of different nodes such as unmanned vehicles, and other assets make this a critical space)
6. Space (satellite)

Due to the relevance of the EMF as strategic scenario to be controlled and defended, innovative assets have to ensure persistency and resiliency to guarantee a continuous service. Unmanned technology has been explicitly developed for such an issue resulting in a cost-effective asset to be integrated with traditional one to achieve global mission tasks. Patrolling

and environment analysis are two unmanned related field. The interoperability between unmanned vehicles with a patrolling vessel extends patrolling capacity of the system lightening operational and life cycle costs, with software embedded in control stations helping officers to track and select targets and decipher malicious behaviour potentially reducing reaction time and increasing possibility of success. To ensure proper efficacy of these tools, tests have to be carried out, hence simulation role gain relevance in this context. The use of unmanned vehicles for environmental analysis extends capability to research and collect data in locations and for mission duration not perceivable by a manned or Remotely Operated Vehicle (ROV), the possibility to achieve mission duration of several continuative days, or even weeks, with reduced human contribution is precious in environmental research related fields.

Autonomous systems are growing in relevance, as much as "The US Congress has mandated that by the year 2015, one-third of ground combat vehicles will be unmanned or autonomous" (Weiss 2011). Interoperability, and hence interactions, of different type of autonomous system either between each other or with manned system is getting more and more an issue. The decision-making process can be generated as simulations to tap the brain of the machine.

For Command and Control (C2) in this research is meant the processes of information gathering, interpreting that information so as to derive a perception of the world, and making decisions on how to respond to that perception (Lakin et al. 1998).

The number and diversity of sources involved in the information gathering process during an operation in EMF, together with data affluence rates make C2 role an increasingly complex and difficult task. In this project C2 is regarded as Software to be federated (SIL) in the simulation federation (Bruzzone et al. 2018).

This introduction highlights the versatility of simulation as a tool to provide a test-bed to conduct extensive trials of dangerous scenarios like EMF in a safe and secure context. Future efforts will be put on development of interoperability between simulator and hardware in the loop via middleware as a step ahead in the direction of a live exercise where real vehicles are used in sea trials during simulations.

As well as for Hardware, work has to be done about SIL as a matter of time management to already build software to be part of a federation.

1 Background

1.1 Critical infrastructures in the Extended Maritime Framework.

1.1.1 Offshore Critical Infrastructure and Simulation

Many on-shore and off-shore installations are operating in the Extended Maritime Framework and need to be addressed. Specifically, it is important to outline that off-shore installation are complex to be protected at a reasonable costs due to their distance from consistent human workforce, as happen with off-shore platforms, off-shore wind farms, underwater pipelines and cables. From this point of view, protective solutions should be activated to cover different domains. It is evident the complexity of this framework and the necessity to integrate different domains, approaches, platforms, systems and procedures within a highly stochastic environment. As matter of facts, the use of M&S represents a very good opportunity to face these challenges and to study this complex context (McLeod 1982, Banks1998, Bossomaier 2000, Waite 2001).

The research group of the author have investigated since long time the protection of critical infrastructures in marine domain and in energy sector. In this thesis, the author proposes a systemic approach devoted to integrate innovative technologies over different kind of platforms to guarantee high level of protection with low costs based on the integration of autonomous systems and AI (Artificial Intelligence).

The research proposes cases related to the protection of off-shore platforms by using autonomous systems able to identify threats through innovative procedures; to this aim, the research includes high level models of the performances of specific algorithms and sensors on autonomous platforms for face recognition of the crew of suspected boats at large distance reducing the risk of false alarms and extending protective area. In this context the use of non-lethal weapon is crucial and this approach represent a very good example to improve the protection as well as safety and reliability.

Indeed, unmanned systems could be employed to extend the range where it is possible to identify the threats, to anticipate them and to increase the time available to adopt countermeasures (Ören & Longo 2008, Bruzzone et al 2011c). As anticipated, this approach is beneficial also to reduce the false alarms, increasing the capacity to discriminate between real and false alarms enhancing protection system credibility.

Today, the innovative unmanned systems technology is often not completely autonomous, but needs to be integrated with other traditional assets (e.g. equipment devoted to be used to intercept, discourage or engage threats) often operated by humans; in addition, the unmanned systems require usually operators and the operative and engagement procedures are driven by the decision makers (Longo et al. 2014). In this research the author adopts the Modelling, Interoperable Simulation and Serious Games (MS2G) for addressing these aspects in order to create a framework that could be used in multiple ways: evaluator of capability assessment for these innovative solutions, training equipment for unmanned systems operators and

simulator for the definition of policies and procedures (Mosca et al 1996, Kuhl et al. 1999, Massei & Tremori 2010, Guo et al. 2011, Bruzzone et al. 2012).

But what is MS2G? Nowadays simulation is evolving and presents new paradigms as Modelling, Interoperable Simulation and Serious Games, which has been developed combining the concept of HLA interoperable simulation with the serious gaming approach. This new paradigm highlights the potential of employing immersive solutions, allowing users to understand and adopt M&S ensuring interoperability standards and high fidelity level of the models developed. It is furthermore necessary to underline that this approach enhances the development of modular interdisciplinary solutions that can be adopted in new application fields (Elfrey 2006, Bruzzone et al. 2014 a, 2014 b, Bruzzone 2018). As a matter of example, this objective can be achieved with the introduction of new educational paradigms to support the evolution of potential users. Considering today opportunities is paramount to foresee future challenges. In facts, complex scenarios that can be addressed by MS2G, combined with modern technologies (e.g. Data Science, AI & Machine Learning, and Internet of Things) allow the creation of innovative contexts, generating, at the same time, new challenges. Technological evolutions shall never be underestimated.

In this document it is reported the experimentation carried out to evaluate the potential to easily train not very skilled operator in conducting such scanning procedures; the experimentation carried out with unmanned systems users allowed to evaluate the effectiveness of the MS2G solution proposed to train the operators as well as to evaluate the benefits provided by augmented reality aid and other specific algorithms (i.e. face

recognition) for what can be referred as wide range detection (Raybourn 2012, Bruzzone et al. 2014).

Among critical infrastructures the ones related to energy industry are particularly significant and it is interesting to note that while technological accidents in the energy industry have been deeply investigated over the last decades, the issue of attacks on energy infrastructures is gaining increasing importance as production and transit areas are evolving into politically unstable and unreliable frameworks. It is therefore necessary to consider energy domain under the security perspective for risk assessment (Burgherr et al. 2015). Indeed, the discussion arises on how to optimize security of critical infrastructure facing budget constraints, technological innovation and new competitive threats. The fields of investigation include Patrolling, Sensor Coverage and Interference, Domain Protection and Blocking (Bruzzone et al. 2009, Megherbi & Xu 2011, Kranakis & Kriznac 2015). To this end, many actors (e.g. EC, US DoD, NATO and Academic Institutions) are investigating innovative options (e.g. Autonomous Systems, Manned Patrolling Assets) for protecting critical infrastructures against asymmetric threats in the maritime environment using multi-agent simulation and interoperable simulation (Enters et al. 2002, Smith 2002, Lucas et al. 2007, Matusitz 2013, Massei et al. 2014, Bruzzone et al. 2015a). Ongoing researches are oriented to the definition of multi-layered architectures for reconfigurable autonomous assets (Brdys 2014), as well as models to support decision making process based on innovative techniques such as Artificial Neural Network and Genetic Algorithms (Longo 2010, Bruzzone et al 2015a) and Game Theory (Ordónez et al. 2013, Vorobeychik & Letchford

2015). The diffuse employment of unmanned systems in new operative scenarios implies the necessity to design innovative training sessions for operators through Live-Virtual-Constructive (LVC) Simulation (Vince et al. 2000, Ratliff et al. 2010, Bruzzone & Longo 2013c) capable of providing rapid and efficient knowledge and skill development for unmanned systems operators (Rowe et al. 2015). This necessity is even underlined by the availability of new technological contents, such as Augmented Reality, with which operators need to interface (Miller et al. 2014). One issue is to manually pilot the unmanned aircrafts remotely by using camera image streaming and sensors information (Yang et al. 2010) in particular for complex operations such as taking off, landing or docking and/or low altitude flight. Over the years, in order to avoid catastrophic damages to assets and increase missions' success rate, simulation-based procedures have been designed for training operators on mission specific operational scenarios in advance (Javaid et al. 2013). Often simulation for adaptive learning is adopted to improve time-critical decision-making skills (Longo 2012, Abhyankar et al. 2014). Therefore, it is of outmost importance the development of common standard in military training and computer game simulators domains to simplify development of new concepts and to increase capability to achieve common goals reducing negative crossover (Kuhl et al. 1999; Svane & Karisson 2003).

1.1.2 Coastal areas

Off-shore installations are not the only critical infrastructures considered in the Extended Maritime Framework. In reference to crisis scenarios it results evident an increasing trend of frequency and scale of natural disasters in many areas of the world (Guha-Sapir et al.2004,

Bruzzone et al. 2018). As a matter of facts, the climate change, population growth together with urbanization, industrial activities and environmental impacts are creating major causes that are expected to reinforce these events in the future (Milkov 2017, Bruzzone et al. 2018a, 2018b). In particular, the urbanisation is rapidly changing the distribution of population around the world: for instance, since last decade, more than one half of the world population lives in cities and this trend is continuously increasing (UN 2014) and many of these towns are located in coastal areas resulting vulnerable to the growing impact of extreme weather conditions (Bruzzone et al.2014b, 2017c).

In addition, the climate change and urbanisation jointly influence stability and are likely to increase the pressure on public authorities to faces these challenges as well as to task military forces for operating in large urban environments in response to instability situations such as:

- Man-made disaster, e.g. explosions, toxic agent contamination (Bruzzone et al.1996b, 2014c, 2015b)
- Large scale natural disaster, e.g. earthquake, flood, tsunami (Bruzzone & Massei 2006; Diaz et al.2013)
- Mass migration (Bruzzone et al.2017b)
- Epidemics & Pandemics (Bossomaier et al. 2009)
- Inner city turmoil (e.g. social unrest, riots) and armed conflicts (Ören &Longo 2008; Bruzzone et al.2011a)

This obviously suggests the opportunity to develop new Decision Support Systems (DSS) based on interoperable simulation to address these needs being able to combine multiple models (Bossomaier & Green 2000).

It should be pointed out that natural disasters generates even more negative synergies with the emerging actual geo-political scenarios where a large number of social and political instabilities are creating very critical environments (Hsiang et al. 2014). In facts the rising number of fragile states at risk of instability and civil conflicts as well as the increase of terrorist attacks are factors that make even more difficult the crisis management (Duffield 2014).

1.2 The complex nature of today missions

Nowadays, Naval Maritime Interdiction framework includes missions of complex, specific and articulated nature. Bright cases are controlling and surveying migrants' flows, especially when accessing south Europe through sea routes, and contrasting piracy.

Performing these activities, the Navies involved need to operate effectively and efficiently through sustainable actions to reach durable results while facing limited resources and diminishing budgets.

Furthermore, the available assets are designed for different purposes and deployment of such units in a non-specific operative point imply a significant effort in term of cost and adaptability and waist of precious assets outside their key specific applications.

Another crucial element is the strong dynamism of the phenomena under analysis. In fact, the players tend to respond quickly to countermeasures while dynamically adapting their strategies, forcing the Navies to revise planning and procedures continuously.

Indeed, the actors are often aggregated in different structures, working both as a single National Navy and as part of different coalitions (e.g., EU, NATO) in presence of other entities (e.g., NGOs, other Navies).

In addition to all these elements, cooperative operations are often very intense, widely distributed over a geographical area and strongly stochastic, which makes planning more difficult. Indeed, modern Navies need to integrate Maritime Interdiction operations (among others) with innovative technological solutions, integrating autonomous systems and advanced data fusion combining different sources (e.g. public information and military coverage); the configuration and calibration of these innovative systems and their integration with traditional assets for the intended use get large benefit from Modeling & Simulation (M&S) to evaluate the overall performance and understand the specific procedures to be adopted and to avoid/anticipate potential integration problems (Massei et al. 2011).

All these issues are subjected to stochastic factors such as failures, false alarms, times, costs, and the simulation is the cornerstone to support the analysis of this innovative operational context.

As matter of facts, the systematic use of the M&S provides strategic support in decision-making process improving both the effectiveness, the flexibility and the robustness of the planning (Bruzzone et al. 2014b; Bruzzone et al. 2013e).

1.3 Autonomous Vehicles

The inclusion of autonomy within unmanned vehicles creates opportunities for new roles and activities and enable possibility to improve operational reliability (Bruzzone et al, 2013c).

There are many ways to define the different kinds of autonomous systems such as UxV, mobile robots, intelligent systems, UAS (Unmanned Autonomous Systems), etc.; in facts there are several types of autonomous systems enabling the possibility to operate over multiple domains (i.e. Air, Sea Surface, Underwater, Land, Space, Cyberspace). In recent years, Unmanned Autonomous Systems are becoming very popular and their capabilities are improving from different points of view:

- Functionalities
- Operational capabilities
- Autonomy levels

One of the biggest challenge for these systems is to address new complex operational roles involving collaborative and competitive tasks among both Machine-Machine Interaction and Human Machine Interactions. These tasks are quite hard since they involve several disciplines such as Artificial Intelligence (AI), Soft Computing, Mechatronics and the need of guaranteeing operational interoperability (Ferrandez et al. 2013; Bruzzone 2010). Many techniques could be applied in the sector of Artificial Intelligence (Swarm Intelligence Fuzzy Logic, Genetic Algorithms, Distributed Computing, etc.) and interesting results in this sector have been also obtained by combining these different techniques (Bruzzone et al. 2008;

Zacharewicz 2008; Affenzeller et al. 2009). The use of IA-CGF (Intelligent Agent Computer Generated Forces) for collaborative and competitive assets has been extensively used with very valuable achievements in different applications (Bruzzone 2010; Bruzzone & Massei 2010; Bruzzone et al.2011); from this point of view it is very important to adopt simulation interoperability standards in the virtual scenario for testing prototypes (Zini, 2012).

Usually, the main challenge for the Autonomous Systems is strongly related to the overall complexity resulting from the combination of the mission needs and the environment characteristics; in Figure 1 several existing solutions are represented according to the combination of these two aspects (Bruzzone et al. 2013b). In facts, Unmanned Autonomous Systems are evolving along years and introduce also new aspects related to the need to introduce the concept of Multi Robot Systems (MRS), that represent the coordination and cooperation among multiple autonomous vehicles (Gerkey et al. 2003). MRS are identified as a mainstream element in the future of military and security operations:

- Localization of chemical or radioactive sources
- Target assignments
- Autonomous driving in dangerous areas
- Perimeter control
- Surveillance
- Search and rescue missions

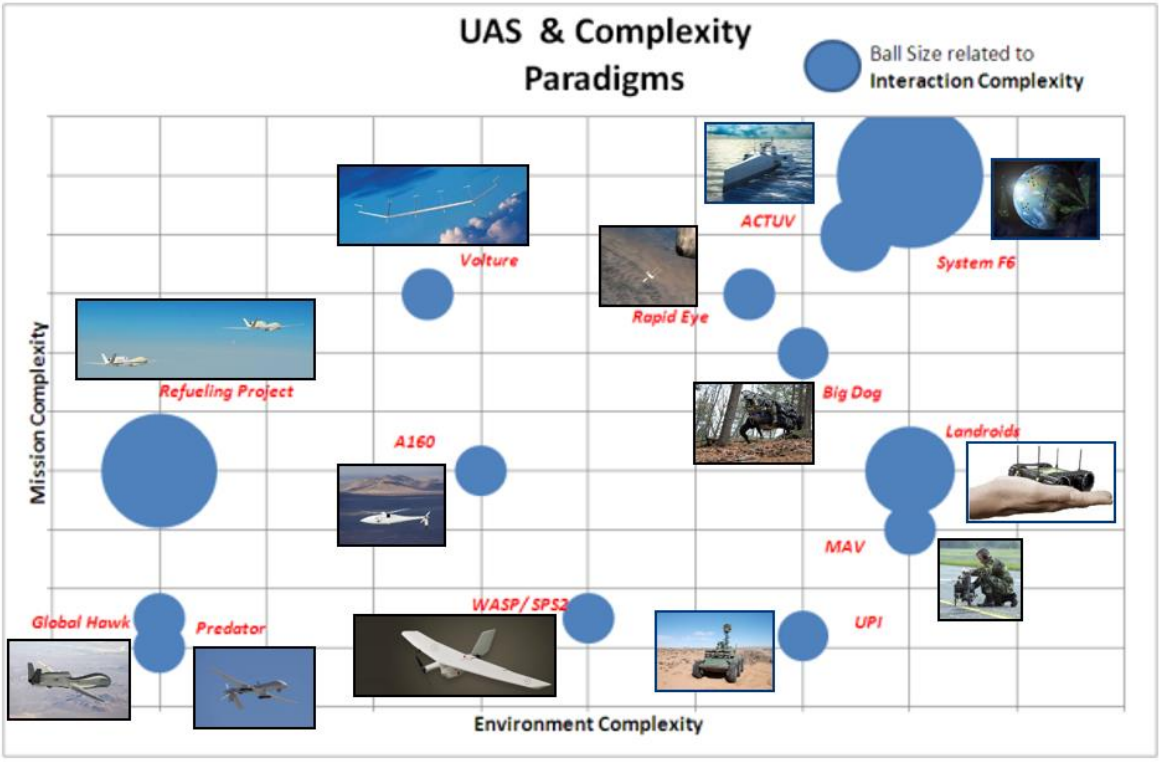


Figure 1: Evolution of Complexity in Mission and Environment among UxV different Projects.

A main classification criterion for all kind of vehicles is based on the Mode of Operation; in general, the simplest mode of operation is with a "manned" vehicle that is 100% controlled by a human on board. Obviously, this category is not applicable to UxV in general as well as to UGV systems, since they are, by definition, "Unmanned", i.e. vehicles without the presence of human operator on-board. Another class to be considered is the "tethered vehicle": this kind of vehicle is 100% controlled by the human operator, but remotely; obviously in this case operating in Line-of-Sight is very common; when such condition is not satisfied, the teleoperation is activated; in this case the full control stays on the human driver, but the guidance is performed by using sensors or cameras, without the Line-of-Sight (Tele-operation).

A step towards more advance solutions is in the direction of autonomous or semiautonomous systems. For instance, semi-autonomous systems have at least one autonomously controlled function; it is therefore evident that the level of autonomy can vary case by case. When autonomy reaches 100%, the mode of control does not demand the presence of a human operator and the mission could be programmed in advance assigning tasks and goals. In the following figure a classification approach for autonomy is proposed.

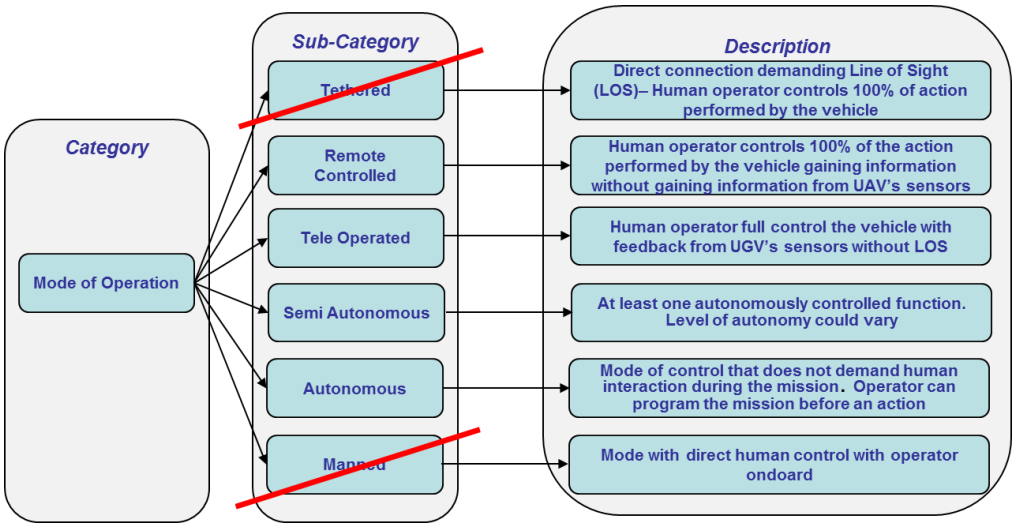


Figure 2: Example of Different Behavioural Modes related to the Concept of Autonomy

In facts the concept of autonomy corresponds to different issues and it is possible to define different kinds of Autonomous Behaviours; indeed autonomous behaviours represent all the actions that are undertaken autonomously by Unmanned Vehicles; for instance Autopilot functions include among the others (Stodola & Mazal 2016):

- Guidance
- Navigation
- Control

- SLAMS (Simultaneous Localization & Mapping)
- Actions to Achieve a Goal
- Prioritizing Tasks
- Activation of Tasks based on Situation Awareness and Threat Assessment

It is interesting to propose the classification system based on the Level of Autonomy (LoA) used by National Research Council and proposed by US DARPA (Defence Advanced Research Projects Agency) using four Levels of Autonomy (NRC 2005):

- Level 1: Manual Operation
- Level 2: Management by consent
- Level 3: Management by Exception
- Level 4: Fully Autonomous

Other classification systems with a higher level of resolutions are existing as presented in the following table (O'Donell 2003; Deyst, & Egan, 2005); in this case the classification of Autonomy level is moving from level 1 up to level 10. The simplest way is the Level 1 that consist on remote control without any decision-making capability. In this case the Line-Of-Sight (LOS) is required. When the automation level rise, the Observation Perception and decision-making ability level increase up to the level 10 in US Army Scale for Future Combat Systems (FCS), where the system is fully autonomous and totally independent without any supervision (Huang et al. 2005).

Table 1: Levels of Autonomy in the US Army Scale for the Future Combat System

Level	Level Description	Observation Perception and Situation Awareness	Decision-Making Ability	Capability	Example
1	Remote control	Driving sensors	None	Remote operator steering commands	Basic teleoperation
2	Remote control with vehicle state knowledge	Local pose	Reporting of basic health and state of vehicle	Remote operator steering commands, using vehicle state knowledge	Teleoperation with operator knowledge of vehicle pose situation awareness
3	External preplanned mission	World model database—basic perception	Autonomous Navigation System (ANS)-commanded steering based on externally planned path	Basic path following, with operator help	Close path following intelligent teleoperation
4	Knowledge of local and planned path environment	Perception sensor suite	Local plan/replan—world model correlation with local perception	Robust leader-follower with operator help	Remote path following—convoying
5	Hazard avoidance or negotiation	Local perception correlated with world model database	Path planning based on hazard estimation	Basic open and rolling semiautonomous navigation, with significant operator intervention	Basic open and rolling terrain
6	Object detection, recognition, avoidance or negotiation	Local perception and world model database	Planning and negotiation of complex terrain and objects	Open, rolling terrain with obstacle negotiation, limited mobility speed, with some operator help	Robust, open, rolling terrain with obstacle negotiation

7	Fusion of local sensors and data	Local sensor fusion	Robust planning and negotiation of complex terrain, environmental conditions, hazards, and objects	Complex terrain with obstacle negotiation, limited mobility speed, and some operator help	Basic complex terrain
8	Cooperative operations	Data fusion of similar data among cooperative vehicles (such as UAVs)	Advanced decisions based on shared data from other similar vehicles	Robust, complex terrain with full mobility and speed. Autonomous coordinated group accomplishments of ANS goals with supervision	Robust, coordinated ANS operations in complex terrain
9	Collaborative operations	Fusion of ANS and reconnaissance, surveillance, and target acquisition (RSTA) information among operational-force UGVs	Collaborative reasoning, planning, and execution	Accomplishment of mission objectives through collaborative planning and execution, with operator oversight	Autonomous mission accomplishment with differing individual goals and little supervision
10	Full autonomy	Data fusion from all participating battlefield assets	Total independence to plan and implement to meet defined objectives	Accomplishment of mission objectives through collaborative planning and execution, with operator oversight	Fully autonomous mission accomplishment with no supervision

In general, increasing the autonomy in UxV requires introduction of more advanced Controls Systems, but allow to assign high level orders.

The advance in technological sector related to sensing, controlling and computing allows to bridge the gaps between manually operated assets and fully autonomous ones (Rohde et al. 2008); this is even underlined by the creation of standard communication protocols for

remote operations (Hazra et al. 2013). The use of Augmented Reality (AR), overlaying computer graphics content to real world visual data, enhances operator situational awareness in these frameworks and his capability to control vehicles, pushing the intuitiveness of User Interface within the C2 station (Vozar & Tilbury 2011; Longo et al. 2012; Bruzzone et al. 2016c).

1.4 Simulation in the maritime domain

In 2009 the USA Office of Naval Research commissioned the Unmanned Systems Branch of the Space and Naval Warfare Systems Centre Pacific (SSC Pacific) to conduct a detailed survey and analysis of current and developing robotic technologies.

The advent of technological innovative solutions such as autonomous systems increased the flexibility of modern Navies during recent years, and while in other sectors they are already very integrated, in this context they are often not a complete operative part of the missions. In facts the capability of autonomous assets could enhance mission success and is necessary to analyse how such innovative assets should be used to finalize parameters as well as to define operational procedures and policies (Bruzzone et al. 2014a, Kaymal 2016).

In the Naval sector, both civilian and military, numerous studies have been conducted in the field of Modeling and Simulation to evaluate the benefits of innovative solutions (Bruzzone et al. 2013d); indeed the marine environment is often very conservative due to the challenges provided by the sea that requires very high reliability in an hostile framework all around the

clock and in all weather conditions; for these reasons the use of simulation to address a priori potential problems is very useful and provides precious insight in advance.

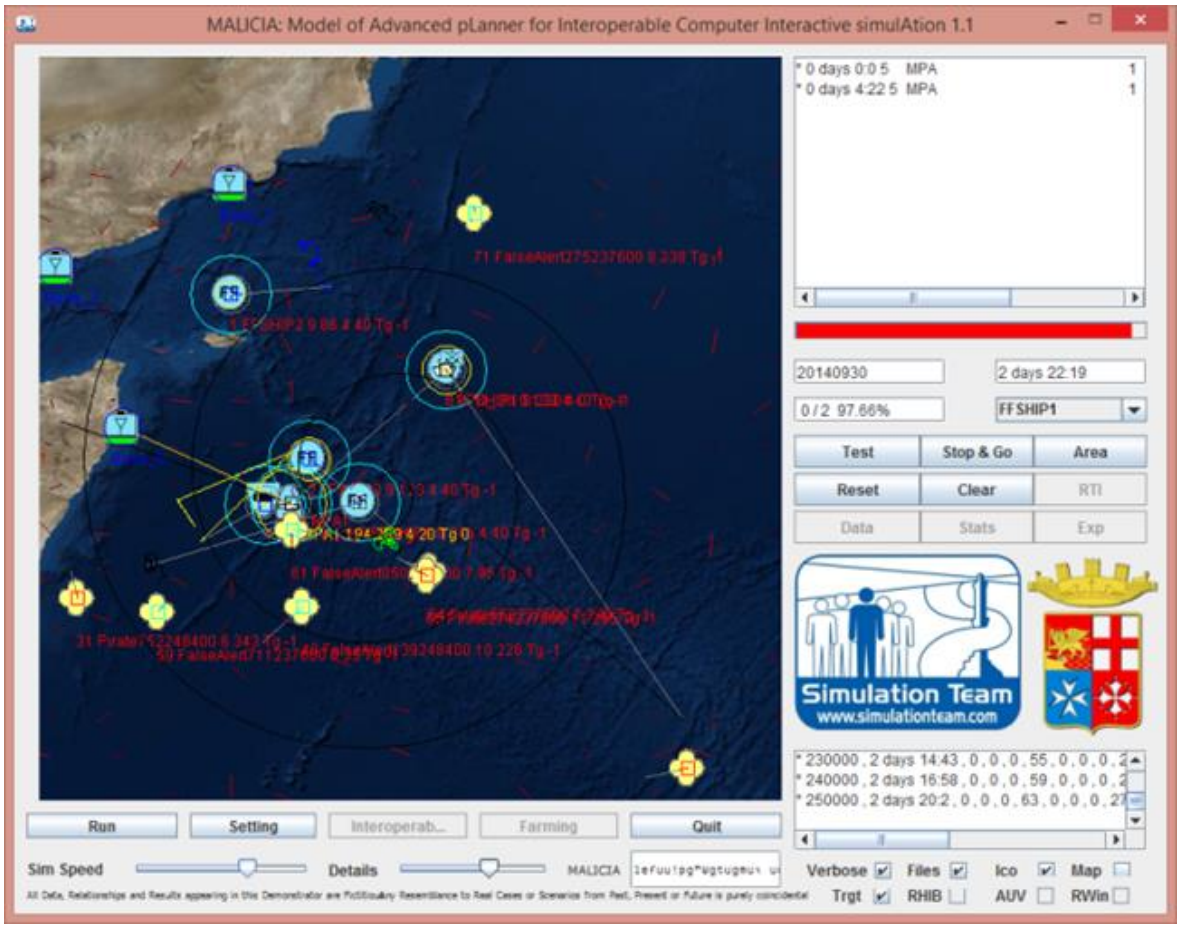


Figure 3 MALICIA GUI

Simulation of maritime operations is thus an advanced and consolidated tool, using sophisticated models to reproduce the actual behaviour of different types of vehicle involved in these scenarios. Among others, specific models of MPA (Maritime Patrolling Aircraft) and UAVs have been developed to study the advantages and possible applications (Brennan & Denton, 2004, Pereira et al. 2009). Indeed, the scenario under analysis is very complex and characterized by total heterogeneity of vehicles and of the environmental conditions that

have a very significant influence; due to these reasons, the simulation is used for planning operations and as support in the decision-making process (Bruzzone et al. 2011b). Indeed, it is fundamental to integrate in the simulation the available models able to reproduce the weather and oceanographic conditions and their impact on the assets and vehicles (Pautet et al. 2005; Delbalzo & Leclerc, 2011; Lundquist 2013). The inclusion of environmental condition effects is beneficial as the scenario analysed consists even of small-medium size boats (e.g. pirates, fisherman) and assets (e.g. UAV, AUV, USV) greatly influenced by weather conditions (Bruzzone et al. 2011c, Slootmaker et al. 2013). Indeed, in specific weather conditions even sophisticated sensors have reduced capability to detect specific kind of targets such as small medium boats (e.g. RHIB) so it is evident the importance to model all of these aspects.

In Maritime Interdiction applications, stochastic dynamic simulation offers many advantages compared to conventional studies, which would require to simplify the problem with limited generalization capabilities. These kinds of models were developed originally due to piracy issues, having a great impact on commercial maritime traffic, estimated between 1 and 16 billion US$ by United Nations Conference on Trade and Development. This leads commanders and policymakers to task scientists to develop decision support tools generating patterns and behaviour of maritime piracy actor (Varol & Gunal 2015). Planning effective activities is even a matter of considering the trade-off between operations costs and security; such tools are based on agent-based models and game theory (Bruzzone et al. 2009, Jakob et al 2012, Jeong & Khouja 2013, Marchione et al. 2014). In fact, such a scenario is very

complex, with different types of vehicles, as surface vessels, underwater vessels, MPA, UAVs, helicopters etc. with different technical characteristics, rules of engagement and differently influenced by boundary and environmental conditions. Simulation re-creates all of these different models interacting with each other by means of IA-CGF (Intelligence Agent Computer Generated Force) (An et al. 2012, Bruzzone 2012, 2013b, 2015a). Intelligent Agents recreate the behaviour of pirates present in the simulation reproducing rational and emotional reactions to patrolling assets (Bruzzone et al. 2015b, Bruzzone 2017) and the autonomous assets follow an action/reaction logic that allow them to interact with each other, thus creating a dynamic simulation (Bruzzone 2015c).

Considering the huge amount of data, interactions and information to be processed in naval operations to evaluate the effectiveness of a certain planning or strategy, the simulation is a very valuable tool (Bruzzone et al. 2011a, Cavallaro et al. 2007). By this approach, the simulator could be able to manage and use effectively unmatched input parameters and to address the uncertainty of the scenario, and within minutes it is possible simulate days, weeks or even months of activity, allowing making multiple replications of the same scene by varying the boundary conditions to understand their influence (Bruzzone et al. 2017a).

Currently these models, originally developed for piracy, are under adaptation to be used in sea border protection and anti-immigration operations.

1.5 Artificial Intelligence applications

Neural Network in the maritime domains have been studied to address a certain number of different application field, ranging from development of artificial intelligence for unmanned vehicle (Zhao et al. 2016), Maritime traffic prediction (Wang et al. 2013; Daranda 2016), Behavioural Classification and prediction (Dabrowksi & de Villiers 2015; Zissis et al. 2015), radar target detection (Zhu et al. 1995), automatic damage assessment (Rose-Perhrson et al. 2000) and even for protection of marine mammals against ship strikes (Jian-Hao 2011).

Automatic Target Recognition tools and methods are widely investigated in different industrial and military fields (Roth 1990, Zhao & Principe 2001). In facts the complexity of this demanding task is to be found in different aspects, such as the necessity of being time responsive, highly accurate and capable to adapt to very noisy environment. The interest in Neural Networks to address this problem is justified by the good adaptability to those constraints and, moreover, due to Artificial Neural Network (ANN) learning capabilities. Target recognition and behaviour analysis using ANN is a hot topic since late '90s, when first experimentation have been carried out. As nowadays, Neural Network were then developed given their applicability in scenarios characterized by high level of noise and changeability, such as moving target recognition in seaport radar images (Zhu et al. 1995; Pasquariello et al. 1998). These tools have been developed to be applied even to real satellite, radar or sonar imageries solving sensor fusion problems (Carpenter & Streilein 1998; Paes & Medeiros 2012) and have been recently applied to real time, real world maritime domain facing the hurdles not present in experimental situation such as degradation, limited collected

examples and great variety in format, influence of weather condition and volume of high resolution imageries (Tang et al. 2015; Verbancsics & Harguess 2015). Some branch of the research world is devoted to comprehend how to limit the number of images needed to properly train a neural network for maritime application, overcoming one of the biggest nowadays issues (Rainey et al. 2016).

The interest of the navies in ANN applications is highlighted by the numbers of research supported in this field by the US Office of Naval Research (ONR) founding six Navy laboratories and several universities and commercial companies to produce many of the processing tools applied in real world engineering problems and further to understand of biological and electronic neural systems investigating both biological and information processes (Miller et al. 1992). Among the ONR research, the most valuable achievements are the Classification networks developed by Dr. Lynch research team (Ambros-Ingerson et al. 1990), development of artificial intelligence for robots ad autonomous vehicles (Saillant et al. 1993) and indeed the contribution to the creation of a signal classification neural network tool developed by the Nobel Prize winner Leon Cooper now used by different DoD contractors as well as applied for credit risk assessment (Bienstock et al. 1982; Cooper & Scofield 1988).

Recent achievements in the naval domain are devoted to enhance situation awareness with data fusion approach for automated remote sensing imagery analysis applied to different sensor types, including Synthetic Aperture Radar (SAR) (Bachmann & Bettenhausen 2002) and Aerial and satellite imagery (Rerkngamsanga et al. 2016), to generate a common

operating picture providing a sound grounding for timely and reliable decision making thus increasing safety, security and readiness. Furthermore, some application is devoted to enhance on-board situational awareness, which nowadays is critical due to the increase of ship autonomy grade and consequent on-board personnel reduction, monitoring ship performances and merging signals from acoustic sensors, video image detection algorithms, integrated spectral sensors providing real time events identifications as fires, gas leaks, structural damages, pipe breaks (Minor et al. 2007).

Behavioural prediction might be expressed in different forms, depending on the final aim of the Artificial Neural Network tool. Indeed, there is a diversification in the applicability of those studies. Accordingly, behaviour might be regarded as a set of physical information about the vessel, as in the case of the ANN developed by Zissis in 2015 and Perera in 2012 in which position speed and course are forecasted using massive amount of data coming from ships Automatic Identification System (AIS). This enables analysis and supervision of single as well as classes of vessels (Bomberger et al. 2006), and used to assist port scheduling. On the other hand, abnormal behaviours may be regarded against probability of having malicious intention (Dabrowski & de Villiers 2015) classifying suspect pirates fusing information including vessels/boats track, contextual elements influencing the behaviour (e.g. time of the day, ocean condition, weather condition, season of year, location) and then feeding a classification network initialized with probabilistic relationship between variables/output. These applications are based on Dynamic Bayesian Networks showing the

feasibility of behavioural identification through tracked data and trajectory analysis based on AIS data (Castaldo et al. 2014; Mazzarella et al. 2014).

Anomalies and suspect behaviours are to date analysed with rule-based tools based on SMEs knowledge and experience, but some steps have been done following the approach of "learning from data" and the consequent use of neural network (Will et al. 2011). Despite the relevance of the phenomena there are few researches ongoing on the use of ANN applied to anti-piracy scenario and even less on maritime illegal immigration detection (Lopez-Risueno et al. 2003; Teutsch & Krüger 2010).

The author research team members have been active along the years on the research for applications adopting ANN for both industrial and military sectors (Bruzzone et al. 1998a & b; Bruzzone 2002); in particular Data Fusion systems have been integrated with ANN in Capricorn and IA-CGF (Bruzzone & Frydman 2007), while applications for identifying behaviours and/or conduct situation awareness have been used in different cases (Bruzzone & Bocca 2008; Bruzzone et al. 2010).

1.6 Augmented and Virtual Reality

The use of simulation for supporting education programs is a much consolidated approach (Ferrington et al.1992; Mosca et. Al. 1995) and even the use of Virtual Reality has been extensively applied in several sectors for training (procedures and equipment for remote operators) (Psotka 1995; Mosca et al. 1996, 1997; Moline 1997; Wilson et al 1997; Stone 2001).

Indeed, once innovative virtual frameworks are created, it becomes possible to use them also to improve maintenance and service in different ways, such as optimization of the service, logistics as well as preventive analysis on the context (De Sa et al. 1999; Bluemel et al.2003). Indeed, the innovative use of Simulation to support service of distributed systems has been effectively applied to aerospace and energy industries (Bruzzone & Simeoni 2002; Haritos 2005).

Figure 1: Concept of Virtual Mock Up for an Educational and Training Aid for AUV Service

Augmented and Virtual Reality could support many aspects, with servicing and maintaining among the most promising since the introduction of these techniques (Azuma 1997).

The use of mobile technologies is very interesting to address distributed systems; indeed the mobile solutions for simulation based training in external logistics have been demonstrated very successful in several contexts confirming the potential of mobile training concept (Bruzzone et al. 2004a, 2004b, 2017b; Monahan et al. 2008; Ally 2009; Lee 2011). Indeed, the interactive Virtual Worlds are effectively enabling new opportunities in training applied to procedures and operations in many sectors (Bruzzone 2009; Raybourn 2014).

In this thesis it is proposed to investigate the use of web technologies and cloud approach to support services in conjunction with AR, VR and M&S. For instance, applications to industrial plants and components based on web technologies and virtual reality are popular from almost two decades and are continuously evolving (Bruzzone 1999; Monahan et al. 2008). Even if these concepts have been investigated since many years, the recent evolution in web technologies is enabling new opportunities in service and maintenance (Bruzzone et al. 1999; Vora et al. 2002), providing the remote users with devices able to evaluate the status of the operator in order to optimize the effectiveness of training and of operation. In this sense, the use of innovative solutions based on the capability to capture physiological parameters remotely (e.g. EEG, muscular tone, cardio frequency) has a great potential in supporting operator and user supervision; from this point of view these researches are very consolidated (Orlansky 1994; Brookings 1996) and are leading to new solutions (De Crescenzio et al.2011; Bruzzone et al. 2016a).

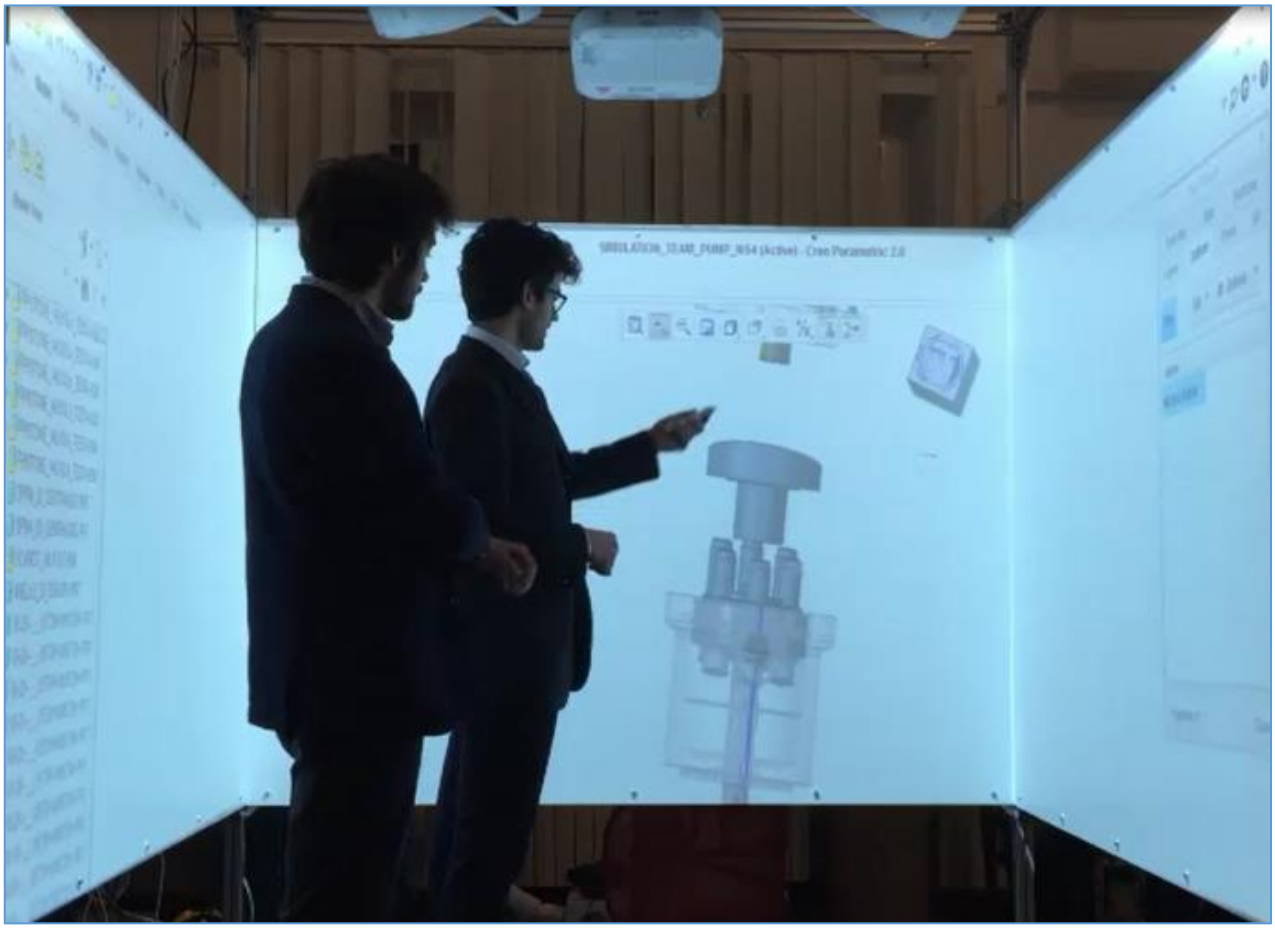


Figure 4 SPIDER: the Virtual Immersive Interoperable Interactive CAVE for Virtual Training and Engineering

1.7 Research Background

During the first year as PhD. Student, tutored by prof. Agostino G. Bruzzone, in order to form a consistent background knowledge, the author focused on Modelling and Simulation related to appliances on Autonomous Systems, Artificial Intelligence and Intelligent Agents. In particular the topics of the researches, in accordance with the purposes identified in the research project, are M&S as a tool to design and support the employment of Manned and Autonomous Systems both for Critical Infrastructure Protection in Extended Maritime

Framework and in space environment. In addition, a branch of the research has been devoted to application of Virtual and Augmented Reality for maintenance and training.

During the second year, the topics of the researches in accordance with the purposes identified in the Research Project have been M&S tools for Decision Support Systems (DSS) in the maritime environment using Artificial Neural Network (ANN). In addition, a branch of the research has been devoted to support both the design and the employment of Manned and Autonomous Systems for industrial applications.

The author had the chance of supervising the thesis of two international students of the MIPET master, on a feasibility study, based on M&S, for the storage of CO2 into the marine environment. The study has been carried out in conjunction with the ERG Power Plant located in Priolo, Sicily, Italy.

The author has been involved in the Visiting Research Program (VRP) of NATO STO Centre for Maritime Research and Experimentation (CMRE) in La Spezia, with 1 year scholarship founded by the CMRE, starting August 1st 2017 ending August 31st, 2018.

Afterwards, the author continued to work within the CMRE as Staff Member as Modelling and Simulation Scientist.

The topic of the research focuses on the design of a simulated testbed for unmanned systems, the implementation of standard procedures and techniques to Design, Verify, Validate and Accredit distributed interoperable simulations and data collection for Decision Support System inside the alliance.

The research activity has been coupled with active participation to NATO NMSG-139 (NATO Modelling and Simulation Group) till its conclusion in September 2017 dealing with the development of innovative techniques to evaluate M&S (Modelling and Simulation) Use Risk. These participation have incliuded the participation to a course at Johns Hopkins University, Applied Physics Laboratories on VV&A and risk computation; the course has been finalized by an exam.

The research activity has been coupled with active participation to NATO MSG-147 dealing with the development of interoperable tools for Civilian-Military cooperation in Crisis Management and Disaster Relief (CMDR).

The following main topic have been addressed in the research activities:

1.7.1 Modelling and Simulation of Manned and Autonomous Systems for Critical Infrastructure Protection in Extended Maritime Framework:

Critical Infrastructure Protection is a rising issues in today world; considering that most of the population lives on coastal area it is not surprising the fact that several of these infrastructures are located within marine scenario. Ports, piping, cables, off-shore and coastal on shore plants are being more and more targeted by asymmetric threats. Employing Autonomous Assets allows to drastically reduce the protection costs but requires to design new solutions. The research carried out along this first year addresses this issue with special attention to off-shore platforms respecting the opportunity to improve threat assessment by innovative solutions. An MS2G (Modelling, Interoperable Simulation Serious Game) Agent Driven stochastic simulation for reproducing a combined used of autonomous and traditional

assets has been developed to identify threats as well as the possibility to use it for training Unmanned Aerial Vehicles (UAV) pilots. As the research goal is to investigate the potential of innovative technologies the models integrate AI algorithms for face recognitions with sensors mounted on rotary wings vehicles as support for protecting offshore platforms. In this case the simulation is mainly devoted to understand the operative advantage of a rotary wing drone employed on off-shore platform for the use of the decision maker, to provide a useful tool for the definition of design requirement of the system and to provide a test-bed to train drones operator performing recognition activities in a hostile environment facing unconventional targets.

One of the simulator proposed for this case study is SO2UCI (Simulation for Off Shore, On Shore & Underwater Critical Infrastructure) and it has been developed by the Simulation Team; SO2UCI is a simulation able to support system requirement definition phase and training on protecting Off-Shore Platforms (e.g. oil rig, gas rig), On-Shore Critical Infrastructures (e.g. ports, power plants, refineries, desalinations plants) and Underwater Critical Infrastructures (e.g. cables, pipelines) from Asymmetric Threats using conventional assets and autonomous systems. The results of the experimental campaign obtained on a test population of unskilled operators have been presented to evaluate the possibility to diffuse the use of such approach without requiring very highly qualified expertise. The experimentation carried out with unmanned aerial systems allowed to evaluate the effectiveness of the models proposed to evaluate the benefits provided by augmented reality aid and other specific algorithms such as face recognition.

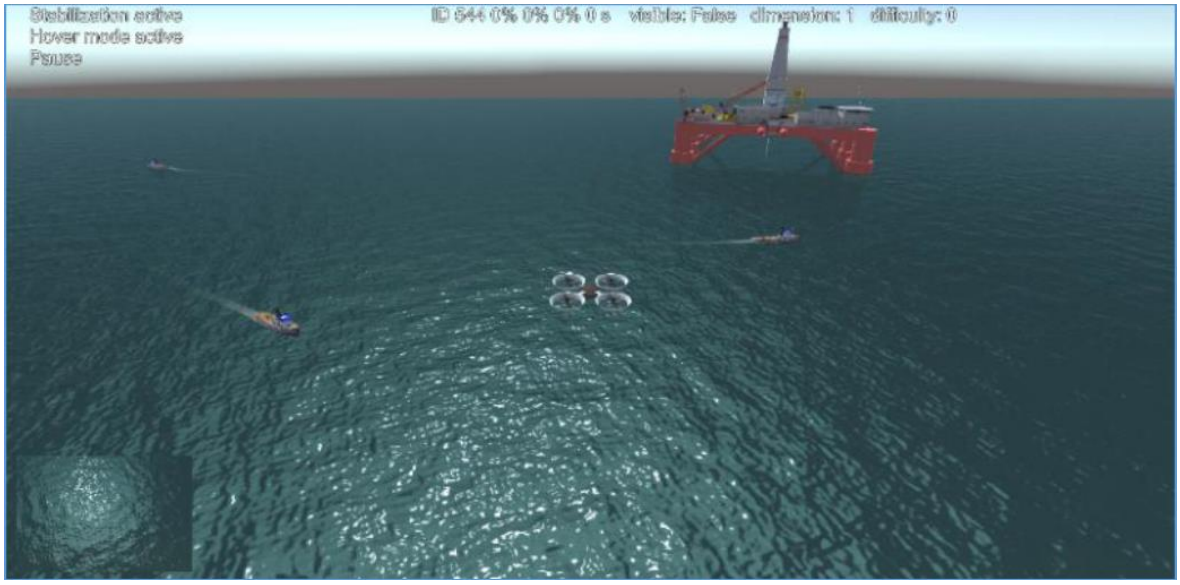


Figure 5 A frame of a simulation depicting a typical Critical Infrastructure Protection scenario.

1.7.2 Modelling and Simulation of Autonomous Systems for Space Exploration Projects

Space exploration is the ongoing discovery and exploration of celestial structures by the continuous improving of space technologies and future exploration missions are expected to establish a solid partnership between human crew and robots. NASA is already employing robot, tele-robots (remotely operated) and Autonomous Systems and have identified critical elements in:

- Technologies enabling Autonomy Capability
- Technologies able to exceed human performance (e.g. sensing, piloting, driving, manipulating, rendezvous and docking).
- Technologies supporting cooperative behaviours among the autonomous systems and humans

- Autonomous Systems increasing human crews' independency from Earth Headquarters

One of the researches of this Ph.D., developed within a NASA project on diffusion of HLA Interoperability Standard and virtual prototyping of Lunar Base, proposes an environment devoted to simulate the use of autonomous systems in space exploratory missions and operations; this study focuses on supporting engineering of autonomous systems and of their innovative artificial intelligences through interoperable simulation.

The approach proposed enables the development of training and educational solutions for use of robots and autonomous systems in space critical environments, addressing different application areas i.e. robotic inventory and warehouse solutions, intelligent space guard systems, drones for supporting extravehicular activities and for managing accidents and health emergencies, to investigate the potential of autonomous systems and their capability to interoperate with other systems and with humans in critical environments.

The simulation developed is intended to investigate and support development of new solutions able to address decision autonomy and collaborative behaviour. Further steps will be devoted to turn the simulator in a tool for testing and validating technological solutions, algorithms and/or methods for space missions.

Along the Ph.D. study period the possibility to work with Italian Satellite builders made feasible the research on employing Nano-satellite for low orbit experiment on cancer cells. The capability of the space environment to alter the cells behaviour seems to be an opportunity for future researches in biology, for diseases such as cancer. This research

highlights the importance of Interoperable Simulation Systems as precious instruments to support and improve space exploration projects devoted to analyses on biologic samples. The research investigates the potential of Modeling & Simulation to reproduce a virtual environment to support Nano-satellite experiments in cooperation among the different stakeholders involved in a space mission, such as scientist, engineers and biologists.

1.7.3 Use of Augmented and Virtual Reality to support Maintenance and Training

Augment and Virtual Reality is enabling new, advanced solutions in a variety of applications and Maintenance and Training (M&T) have demonstrated great potential of successful AVR application.

Many researches address creation of applications to support service and maintenance of distributed systems servicing industry and individuals and introducing new capabilities for training of operators, remote control and service support.

This Ph.D. thesis presents a case study devoted to lead the introduction of innovative M&T solutions in industrial and health care system.

The researches carried out identified a specific case study in service for distributed systems. In particular the analysis addressed tanks, containers and equipment used to provide O2 to industrial operators, Health Care Infrastructures and individual patients at home. In this case, the components/systems move from simple O2 tanks to cryogenic containers and to respiratory devices. In addition, the application field include industries, public institutions and consumers.

1.7.4 Decision Support System in the Maritime Environment using Artificial Neural Network

In the framework of MALICIA (Model of Advanced pLanner for Interoperable Computer Interactive simulAtion) Project, a research has been carried out to use stochastic discrete event simulation tool for supporting decision-making process in Maritime Interdiction operations by the MMI (Marina Militare Italiana).

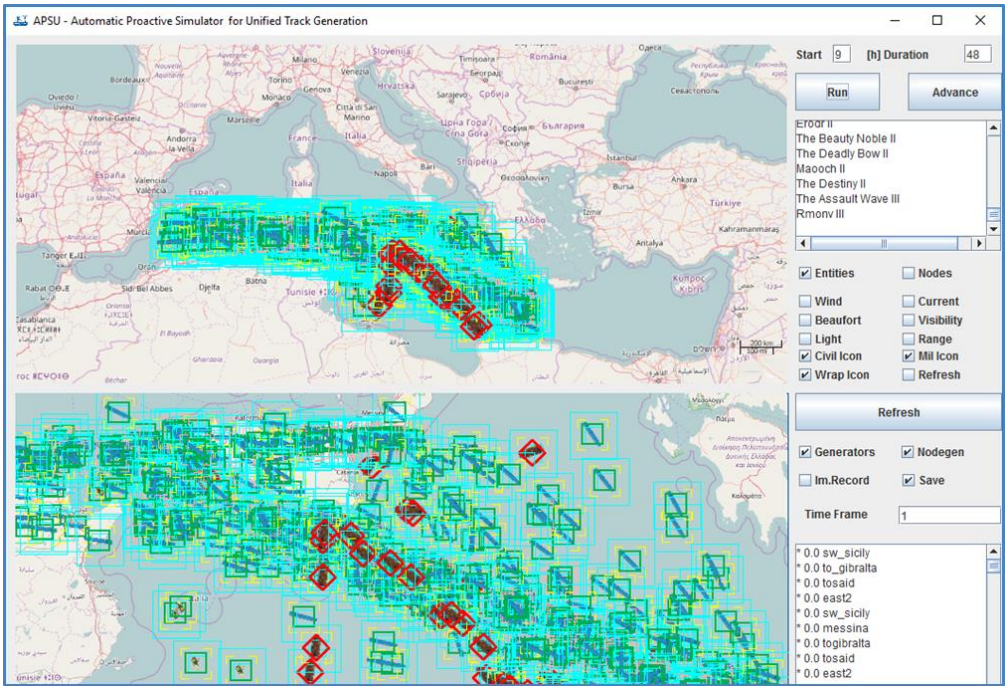
The code, originally intended for addressing anti-piracy operations, contains an illegal immigration interdiction module and ship malfunction identification module based on Artificial Neural Network. The M&S tool is designed to be installed on MMI experimental C2 (Command and Control) system.

The author finalized an ANN for detecting and identify critical aspects related to surface vessels, using data related to the combination of track evolution, manoeuvring and boundary conditions (e.g. visibility, wind, current, etc.) to identify vessels conditions. The objective set by MMI was to smoothly change course after detecting an immigrant boat to avoid to be involved in Search and Rescue operations, according to the situation of the maritime traffic affecting the nature of the course change (e.g. early change of course, no ships with AIS on board in the surroundings, etc.); the results were very promising (around 80% of proper detection of such cases among thousands) even though is necessary to extend this study to carry out other further investigations with real time data.

In similar way the analysis allowed to investigate if a cargo is affected by a malfunction forcing him to return back, or simply to slow down or to change final destination; obviously

this situation is simpler and the ANN performance are highly satisfactory (approx. 94% of success).

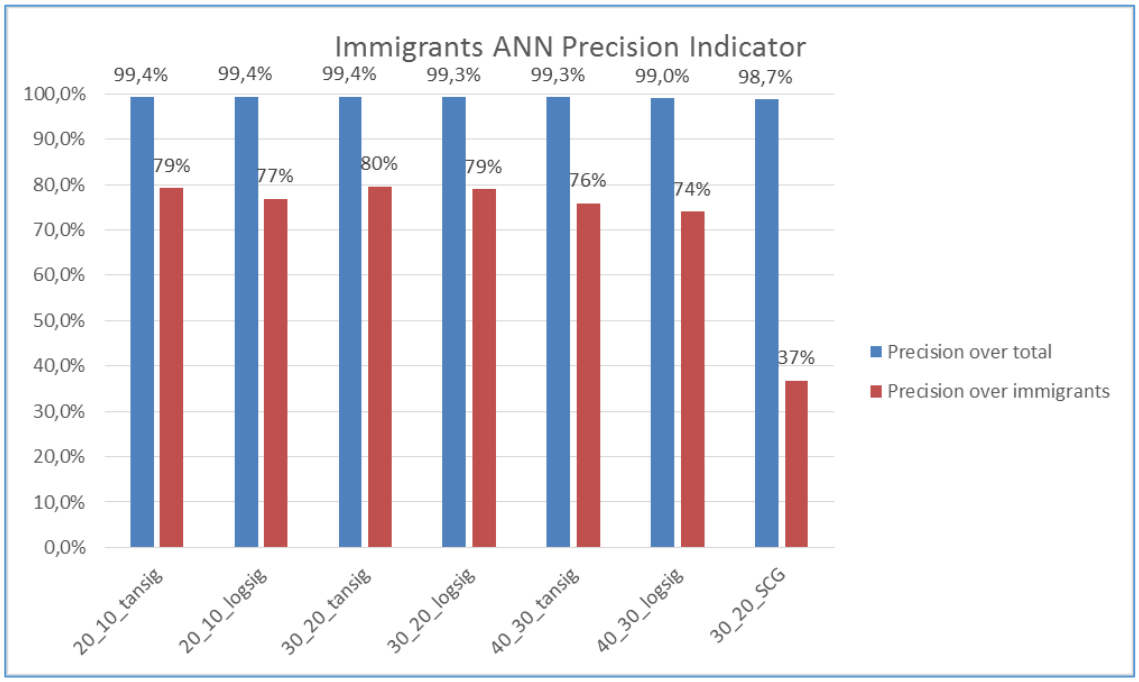
Due to the classified nature of the data required to train the neural network a discrete event stochastic simulator has been developed for feeding the network. The system is based on unclassified data to reproduce a scenario in South Mediterranean where there is presence of Cargo Vessels, Small medium Size Boats as well as Immigrants surface units such as RHIB (Rigid Hull Inflatable Boats).



Simulator feeding the ANN

The developed networks are feedforward, backpropagation neural networks, with two intermediate layers (named Hidden layer). The ANN architecture has been refined through a test campaign devoted to investigate the number of neurons, the training algorithm and the

type of neuron transfer function. The neural networks have been developed using Matlab NNTool.



Performances of the Immigrant detection ANN

The results showed a subtle influence of the number of neurons, with the best solution being first and second hidden layer of respectively 30 and 20 neurons; whereas adopting Log-Sigmoid transfer function has a slightly negative influence on ANN performances.

On the other hand, adopting SCG training algorithm resulted in a dramatic drop in network performances.

The analysis clearly led to the definition of the final architecture of the ANN, whose characteristics are:

- 30 Neurons in the first Hidden Layer and 20 in the second
- Bayesian Regularization training algorithm

- Tan-Sigmoid neurons transfer function

1.7.5 M&S to support design and employment of Manned and Autonomous Systems in for industrial applications

The aim of this research is to evaluate the possibility to use mobile robots for performing dangerous operations inside a plant and thus replacing human activities.

The research is included in the framework of FASOLT (Foremost Autonomous Solutions for Operations in industriaL plant) project and addresses specific topics related to the Pre-Feasibility Study on the introduction of a new UGV System for industrial indoor operations. The activities are devoted to address the following topics:

- Definition of Goals and Expectations for the new UGV System
- Definition of Hypotheses and Constraints related to Operations, Environment and Boundary Conditions
- Survey on Existing Technologies, Autonomous System Configurations, Platforms
- Significant Examples and Experiences, carried out using Autonomous Systems that could be interesting for the current case study
- Synthetic List of platforms potentially compliant with the Problem
- Preliminary Overview of UGV Operator Requirements and Regulations to be Addressed
- Preliminary Overview of Tailored Solutions for the Case Study

- Preliminary Overview on Feasibility, General Performance, Flexibility, Extensibility to other operations/plants/markets
- Preliminary Overview on Capability Assessment, UGV Operational Modes
- Roadmap of this new UGV solution for demonstrating the concept by a preliminary prototype, setting a pilot and proceeding in the Development
- Preliminary Analysis on costs and times to put the new UGV system into operations
- Preliminary Analysis on Risk Reduction, UGV Advantages and Criticalities
- Summary of Overall Benefits, Open Issues and Gaps

This approach led to the identification of the main autonomous platform characteristics and the expected degree of autonomy to face industrial plant challenges.

The research is expected to provide a guideline and roadmap for future development of such UGV solution for creating an industrial UGV.

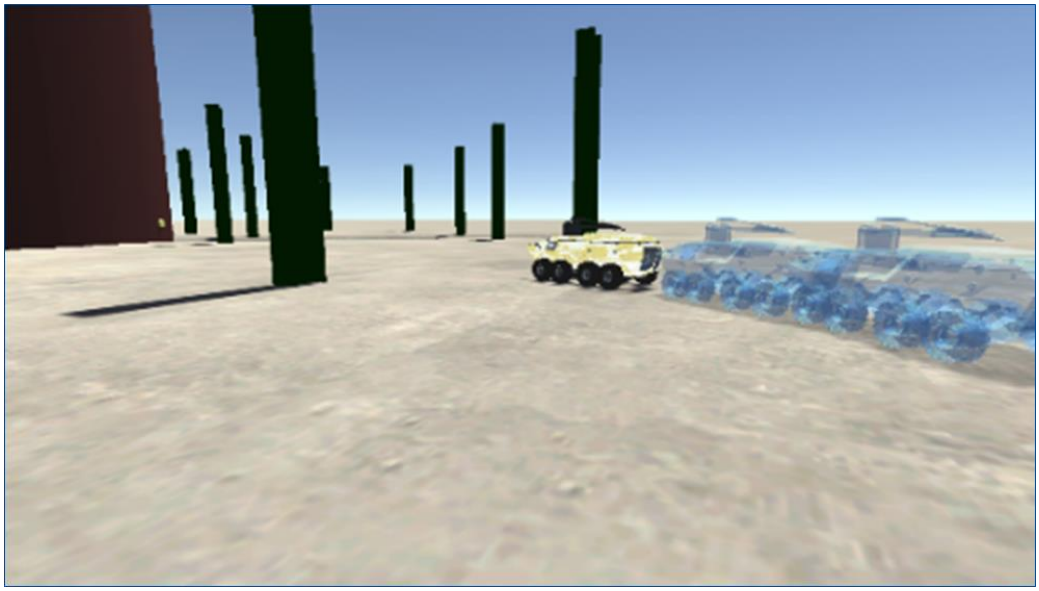


Figure 6 Virtual prototype of the proposed solution in a lightweight Virtual Environment

1.7.6 Definition of M&S Methodologies

The activities related to the Visiting Research Program at CMRE are subdivided in two main branches.

The first is the institution of a methodological framework to support interoperable simulators Development Team, based on advanced Verification, Validation and Accreditation (VV&A) standards. To this end two guides and three templates were produced to drive conceptually and methodologically the Development Team, the V&V Agents and the Accreditation Agents throughout the Federation life cycle, from the definition of the end user needs to the Acceptance assessment.

At the present day, the initial phases of this methodology have been completed, leading to the design of an experimental framework to carry out single federates V&V as well as federation integration testing.

The second branch deals with the design of an evaluation methodology based on simulated testbed for border surveillance platform made of manned and unmanned assets. At the moment the research led to the definition of benchmarks and KPI for the evaluation of Platform performances.

1.7.7 M&S Testbed for Autonomous vehicles

This research activity has been performed within the framework of ROBORDER H2020 project.

The author followed this project since its beginning, the first tasks have been the definition of an evaluation methodology for platforms of autonomous vehicles based on simulation; a

first heavy involvement of the projects participants has been required to define the test plan, as the author team is leading the evaluation and live/simulation-based demonstrations WP. Successively the author has been working on the M&S capability itself, adopting DSEEP IEEE 1730 standard; the DSEEP is recognized as a standard of interest from the NATO. At the moments, needs and objectives have been defined, a set of simulation scenarios have been developed together with the Law Enforcement Agencies involved in the project; from the scenarios, with the knowledge obtained from the technical partners, the conceptual model of the robotic platform has been developed. This has hence lead to the definition of a detailed requirements set which is now driving the design of the federation.

As mentioned, the activities required a consistent involvement of the partners of the project; in addition to the technical tasks briefly described above, engaging and managing partners has been one of the author responsibilities.

The next steps in the development of the M&S federation will involve the integration of Hardware and Software in the Loop (HIL/SIL) to allow a seamless connection of the simulation capability with the architecture, complementing the analysis of the system performances during live real operations for analysis and decision support purposes. To this end the M&S team is currently developing the Federation Object Model.

1.7.8 M&S for supporting logistics operations in NATO

This research activity is focused on the verification and validation of M&S based tools for supporting the strategic and operational planning of logistics operations. This research will

eventually lead to the definition of future required capabilities for decision support in the framework of the logistics of the military operations.

2 Marine Decision Support Systems

Among the problem of interoperability, the issue of having a data analysis capability interoperable with a decision support system is a major key in the defence domain, and in particular in the marine environment.

This section of the thesis proposes the use of constructive simulation as test bed to virtually experiment the validity of a decision support system devoted to plan the patrolling paths of a set of assets in naval operations. The test case proposed is based on anti-piracy scenarios and integrates a discrete event simulator with an Asset Allocator Decision Support System (AADSS) through web services in order to keep them aligned among themselves as well as with the existing situation. The author included description of the proposed architecture that guarantees flexibility in terms of interoperability with other systems.

Today the availability of big data, new models and high performance distributed computational power is enabling innovative solutions for decision making in a wide spectrum of applications. From industry to defence, as well as in very specific areas, the planners are evolving culturally in terms of capability to use evolved ICT solutions integrated within their decision processes. Often these resources are enablers for finalizing more quickly more reliable plans; it is evident that these elements are pushing forward the development and adoption of new generations of Decision Support Systems (DSS) able to integrate simulation and other planning methodologies and optimization tools. These conditions are also present in defence and homeland security generating a growing

importance of these methodologies for major entities in the sector (Bruzzone et al. 2011b). In general, these integrated solutions could be applied over a wide spectrum of scenarios involving actors playing their role over different domains (Bruzzone et al. 2011c, An et al., 2012; Sujit, Sousa, & Pereira, 2015). The evaluation of optimal solutions for such complex non-conventional scenarios requires the ability to evaluate several alternative plans against courses of actions (Richards, Bellingham, Tillerson, & How, 2002; Bruzzone et al. 2011a).

As anticipated Decision Support Systems fulfil their potential by being integrated with modelling and simulation and there are consolidated experiences in this sector (Bruzzone & Signorile, 1998; Tulpule et al., 2011; Tulpule et al. 2010; Longo F., 2012; Bruzzone 2013; Grasso et al. 2014a). Indeed, interoperable simulation supports the evaluation of performances and hypothesis inconsistencies between DSS and the real world.

Modeling & Simulation is thus used to evaluate in details the effects of decisions and planning proposals suggested by the smart planners and to measure their resilience respect stochastic external factors (Medeiros & Silva, 2010; Cavallaro & Melouk, 2007; Bruzzone & Mosca, 2002; Massei et a. 2011) as well as for VV&A purposes (Bruzzone, 2002; Balci, 1998). In this section, the author proposes this approach for supporting patrol planning over an oceanic area for anti-piracy missions. A route optimizer based on genetic algorithms to increase the probability to prevent pirate actions has been made interoperable with a stochastic discrete event simulator focused on evaluating the fitness and supporting the decision maker in finalizing the plan. This study addresses these issues within an anti-piracy mission in order to provide the decision makers with an improved capability in finalizing

their patrol routes with respect to many boundaries conditions including attack probability, weather forecasts, available asset characteristics, deployment, etc.

2.1 M&S and path optimizer

As anticipated the study is about a solution for planning patrolling over an oceanic area within anti-piracy operations. The proposal is integrating a route optimizer based on genetic algorithm (AADSS), which reduces the probability of pirate actions, with a stochastic discrete event simulator (JAMS2) focused on evaluating the fitness and supporting the decision maker in finalizing the plan (Grasso et al.2013). JAMS2 (Advanced Marine Security Simulator) is the simulation model resulting from simplifying PANOPEA; this simulator was created to reproduce the whole traffic over large areas by Simulation Team (Bruzzone et al. 2011c, Bruzzone et al. 2011d). JAMS2 has been adapted to respond dynamically and quickly to the need of quantitative evaluation of the performance for a DSS (Decision Support System) in anti-piracy scenarios. The simulator executes the path proposed by the Optimal Asset Allocator embedded into the AADSS reacting dynamically to contingencies and requests received by the vessels to investigate and inspect suspect boats. The vessels in the simulator are directed by IA-CGF (Intelligent Agents Computer Generated Forces) developed by Simulation Team for a wide spectrum of applications and operate autonomously based on the situation awareness resulting from their C2 status (Bruzzone, Tremori, Massei, 2011e).

The simulation allows to check the path robustness and efficacy within the proposed piracy scenario. The mission environment used for this case study is the Indian Ocean. JAMS2 adopts stochastic discrete event agent driven paradigm in order to test the effectiveness and efficiency of the AADSS (Asset Allocator Decision Support System); this is achieved, as anticipated, by simulating the mission over a time frame based on the patrol plan assigned to each vessel of the coalition.

JAMS2 simulates threats and asset behaviour based on external conditions and operating states; appropriate target functions are implemented in the simulator for evaluating sensor performance and platform capabilities with respect of the dynamic evolution of the boundary conditions (e.g. radar efficiency versus weather conditions). In JAMS2 the real threats as well as the false alarms are generated based on probability matrices based on historical data; these data could be made consistent with the ones used by the AADSS for the planning or could differ in order to evaluate planning robustness (Grasso et al. 2014b); the IA-CGF directs the reaction of the assets based on existing ROEs (Rules of Engagement); in general these assets correspond to Frigates or Destroyers that could proceed by themselves or, more often, by activating their available resources; each asset has its own configuration which could include UAVs (Unmanned Aerial Vehicles), Helicopters, and RHIBs (Rigid Hull Inflatable Boats); therefore the JAMS2 assets and resources structure are able to model also other type of assets such as Patrolling Aircraft, AUV & gliders, Long Range UAV, Gliders etc. for more extended scenario. In order to carry out detection, classification and, when

applicable, engagement of the suspect boats, the assets should apply specific procedures that could affect the assigned plan including deviations, delays, changes, etc.

The false alarms are included in the simulation to evaluate the patrolling robustness to external phenomena. Obviously, the simulator provides detailed metrics for quantitative evaluation of the solution proposed by the Asset Allocator; in addition, JAMS could be used also to support training and capability assessment over these scenarios. The main goal is to evaluate potential inconsistencies between hypothesis used in the Assets Allocator and the real world simulated by JAMS. The simulator, in addition, could be used to play the role of the "real world" to test and validate planning proposal and it could be used to conduct what-if analysis directly by the decision maker. As anticipated the mission environment corresponds to the West Indian Ocean and it is covering a wide geographic area of around 1500 by 1500 Nautical Miles with four patrolling surface vessels able to deploy other resources (i.e. helicopters, UAV, RHIB) for investigation, inspection and engagements of potential threats. As anticipated the current implementation of JAMS2, in Java, is derived from PANOPEA and IA-CGF and is designed for being interoperable through High Level Architecture Standard (HLA). Note that this characteristic is not yet activated due to the nature of the structure of the AADSS working through web services and due to the priorities in tailoring it with respect to the available resources for this initiative.

The simulator has been tested through virtual experimentation by applying Analysis of Variance techniques (ANOVA) on the proposed scenario (Kleijnen, 2007; Montgomery, 2000; Longo, 2010; Telford, 2012). The results of the experimentation campaign are used in

the process of Verification, Validation and Accreditation (VV&A) of the Asset Allocator (Bruzzone 2002, 2017).

Currently the vessels and boats are modelled as surface elements (friends, foe, neutral) characterized by dynamic behaviours. As anticipated the simulator includes the assets' reaction to detected threats and action to be undertaken for suspect threats. In terms of use mode, JAMS2 is currently available for different applications; it could be used to support AADSS for the Asset Patrol Optimization as well as for educating and training planners in operational planning and related improvement and dynamic reorganization by using innovative tools like the ones proposed here. The evaluation of the proposed plan respect risks and stochastic factors is achieved by replicating JAMS2 simulation runs; this is done just by changing random seeds to finalize the ANOVA. JAMS2 results and to measure the AADSS plan, in terms of:

- Robustness
- Responsiveness
- Feasibility
- Actual Duration
- Actual Cost
- Scenario Awareness
- Area Coverage
- Detections
- Capability to inspect and/or Engage Targets

- False Alarms
- Overall Success of Patrol Mission

JAMS2 efficiency in terms of computational time has been tested to evaluate the possible dynamic interaction with the genetic algorithm embedded within the AADSS as proposed in Figure 1 (Bruzzone et al. 2013b; Grasso et al. 2014b).

The JAMS2 implementation is based on Java NetBeans to be able to operate over multiple Operating Systems.

The integration with AADSS is obtained sharing configuration and solution Dbase through a web service.

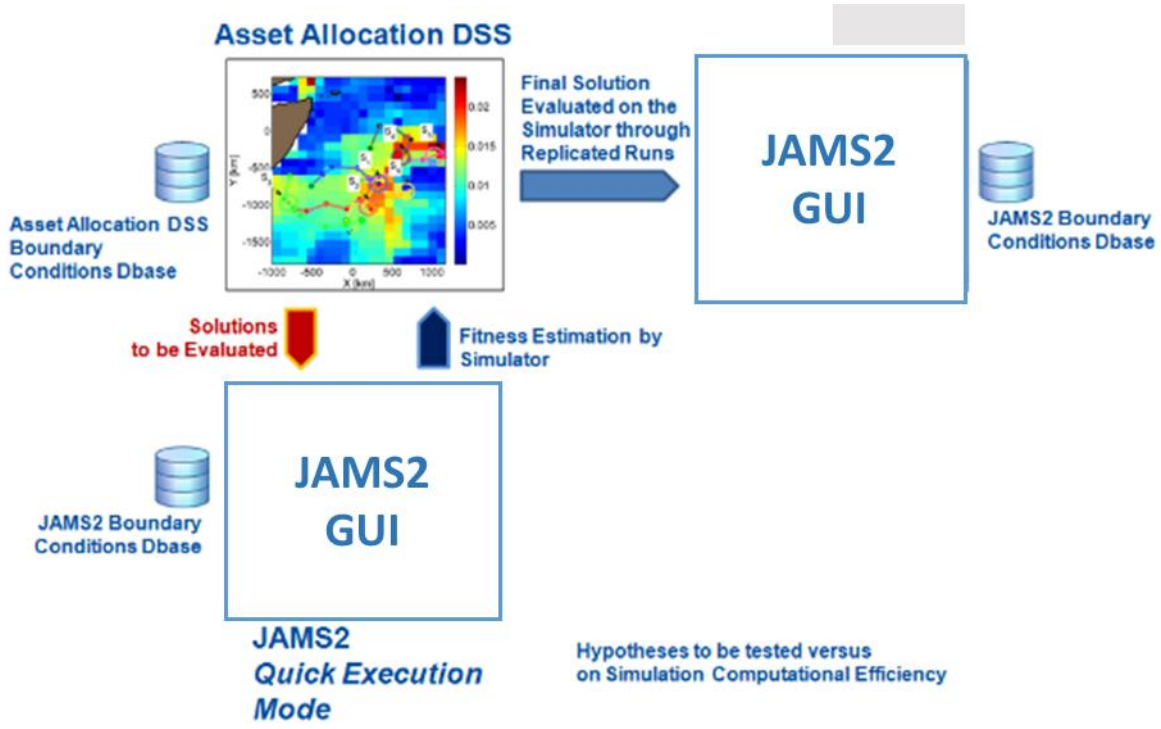


Figure 7 JAMS2 Dynamically Used With the Asset Allocator

In the future, enabling JAMS capability to be connected to an HLA federation could make possible to operate both as stand-alone system and federated with other simulators.

The Graphical User Interface (GUI) is designed to tune simulation parameters, such as replication runs, random seeds and additional boundary conditions, and to execute the simulator. Furthermore the GUI is useful in validating the simulation by observing simulation runs in terms of dynamic behaviour of assets, resources, false alarms and threats. JAMS2 is enabled to run in real time and fast time. Statistical distributions, such as risk map for threats, and weather databases are used during simulations by applying Monte Carlo techniques to generate discrete events and corresponding actions/behaviours. Threats and false alarms adopt stochastic behaviours reacting dynamically to assets evolution and Intelligent Agents (IA) are used to reproduce sophisticated behaviours for small/medium size boats in order to react to the patrol actions and policies within the area suggested by the AADSS.

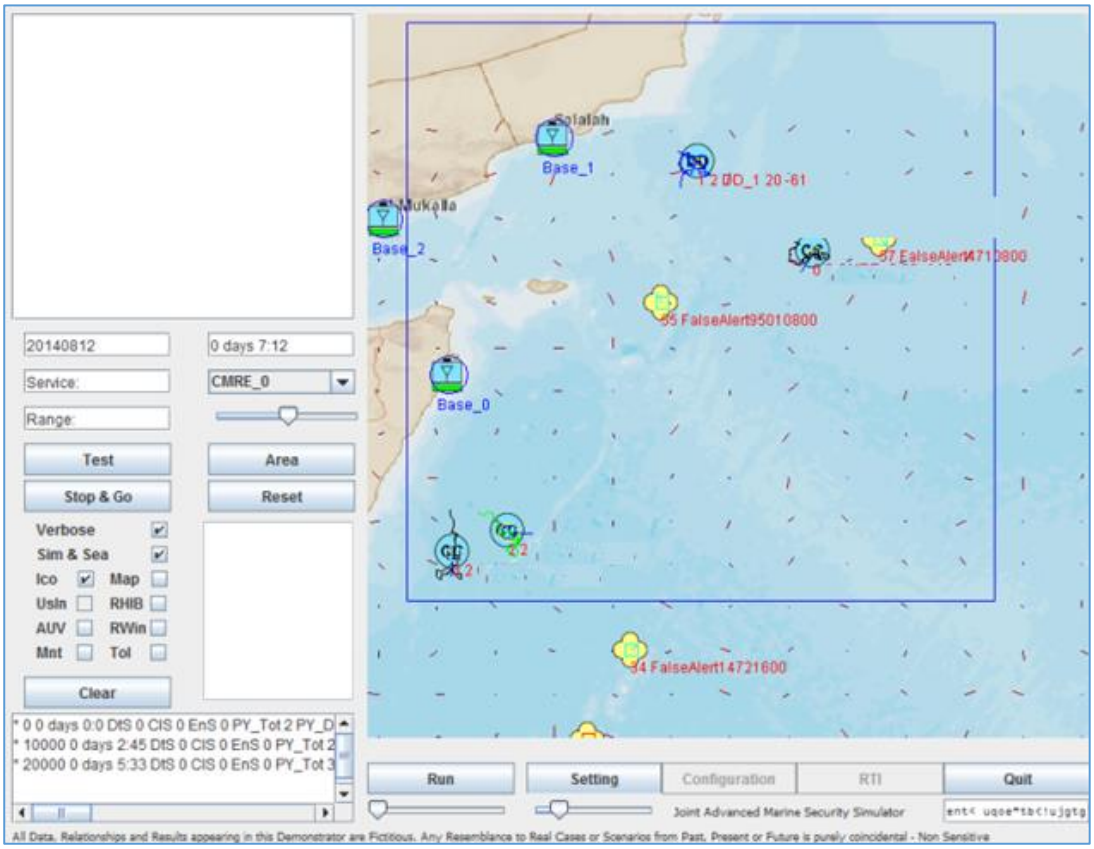


Figure 8 JAMS2 GUI

In a similar way the agents controlling the patrolling vessels adopt their different behaviours based on their situation awareness and their specific characteristics; in general the IA controlling the patrol units could decide among different alternative modes such as:

- EXE: execution of the planned path
- CLA: use of their resources for target identification, classification and/or engagement, deviating from the planned path
- RQS: request external support for target identification, classification and/or engagement

- RES: restoring the assigned planned path after contingencies

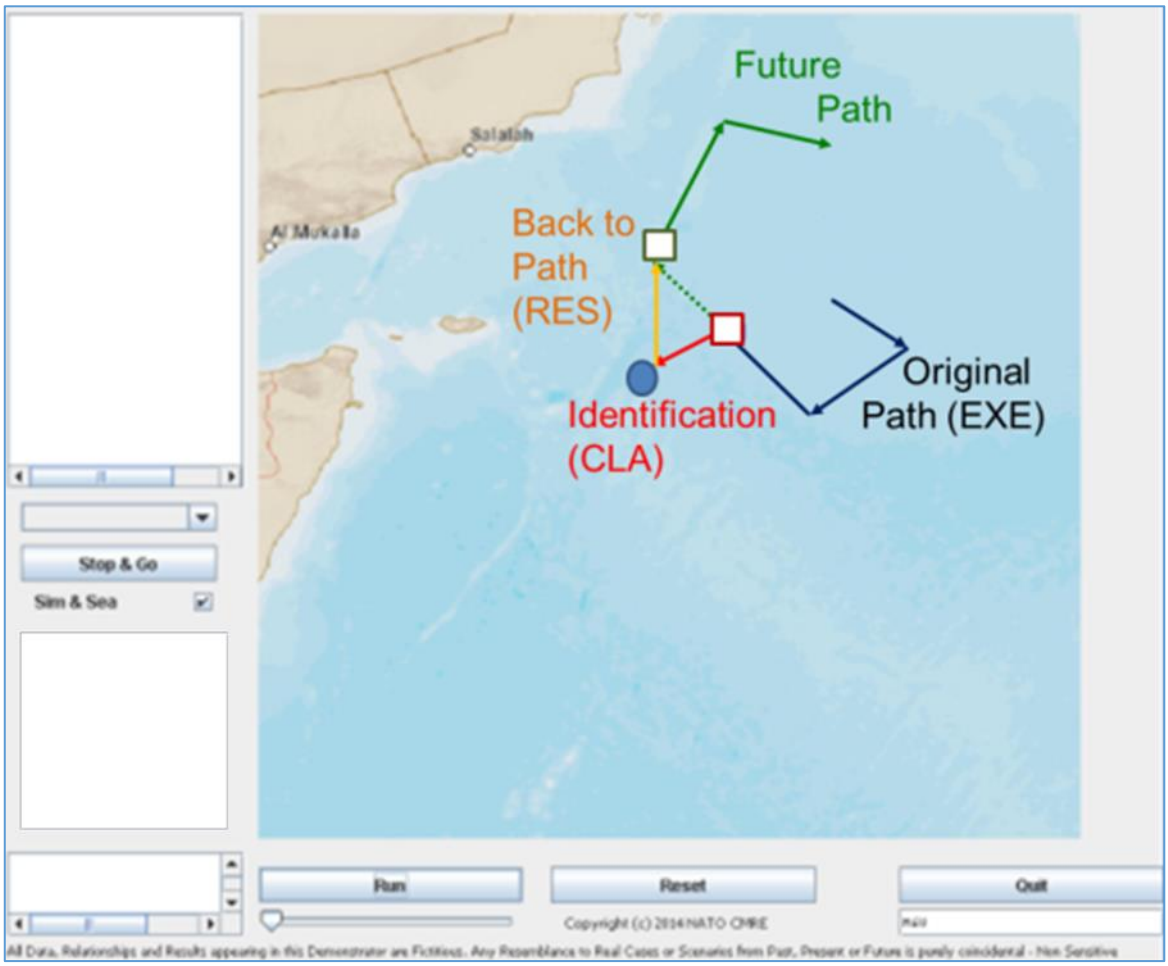


Figure 9 Asset Undertaken Actions and Operating Modes

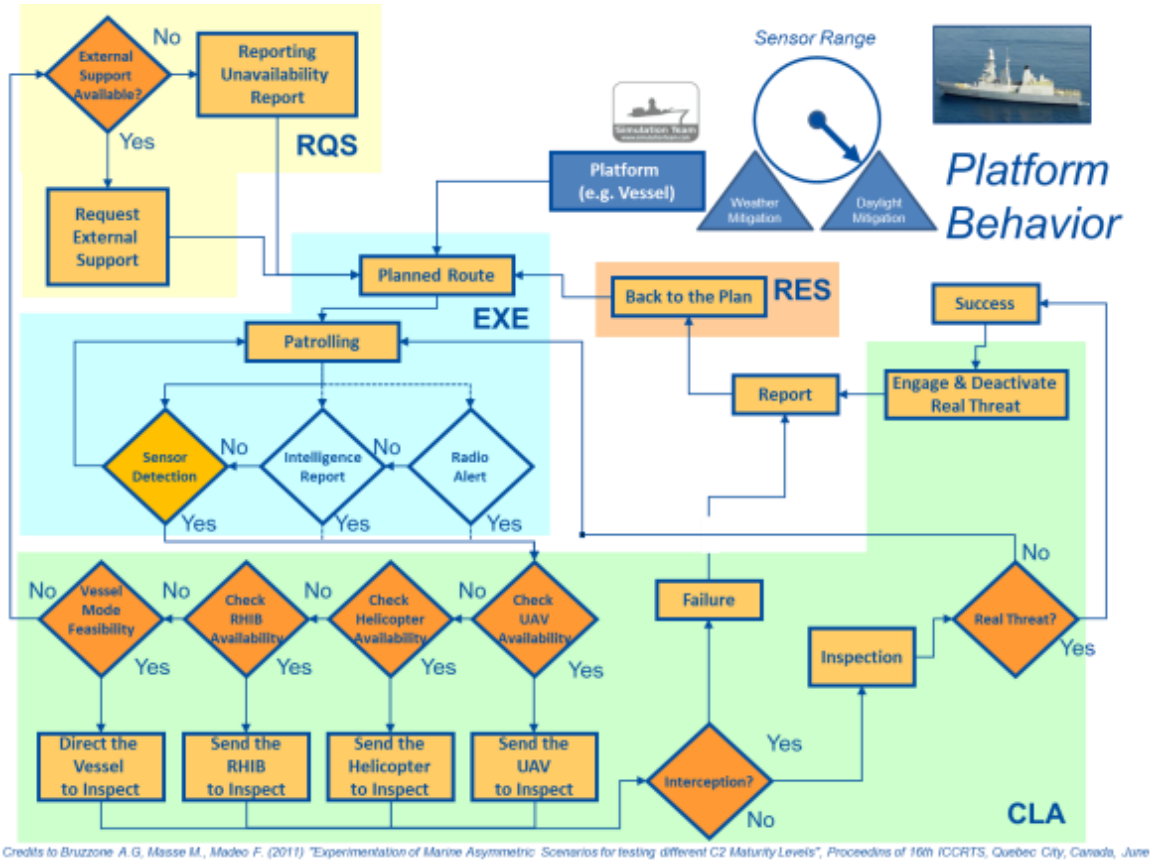


Figure 10 JAMS2 Platform Behaviour

Figure 9 shows the visual representation in the GUI of the policies adopted by the IA interacting with targets.

The current release of JAMS2 does not simulate intelligence reports and radio communications contrary to PANOPEA (Bruzzone et al. 2011d); basic rules are implemented in terms of priorities in using the different assets, i.e. to assign some entity to inspect a boat the IA select the proper choice based on the available resources and target distance (Figure 10).

The capability to simulate different shared resources in the scenario is necessary to create complex autonomous behaviour; this is critical in developing a tool whether for training of operators and officers, for testing Rules of Engagement (ROE), and/or to support analysis.

2.2 Targets

Targets represent a possible risk source. Indeed, the behaviour, as for assets, is based on external conditions and operating states. Targets are characterized by importance factors, hiding capabilities, status and class of boat; both real threats (pirates) and false alarms (small/medium sized boats) are generated based on risk maps defined by historical data and simulated using Monte Carlo techniques. In the simulator only asymmetric assets are implemented, nonetheless JAMS2 structure allows the implementation of other types of targets for different scenarios. The following target operation modes are implemented in the simulator:

- REG: Regular behaviour
- NRE: Non-reactive behaviour
- COP: Cooperative behaviour
- NCP: Non-cooperative behaviour
- FOE: Aggressive behaviour

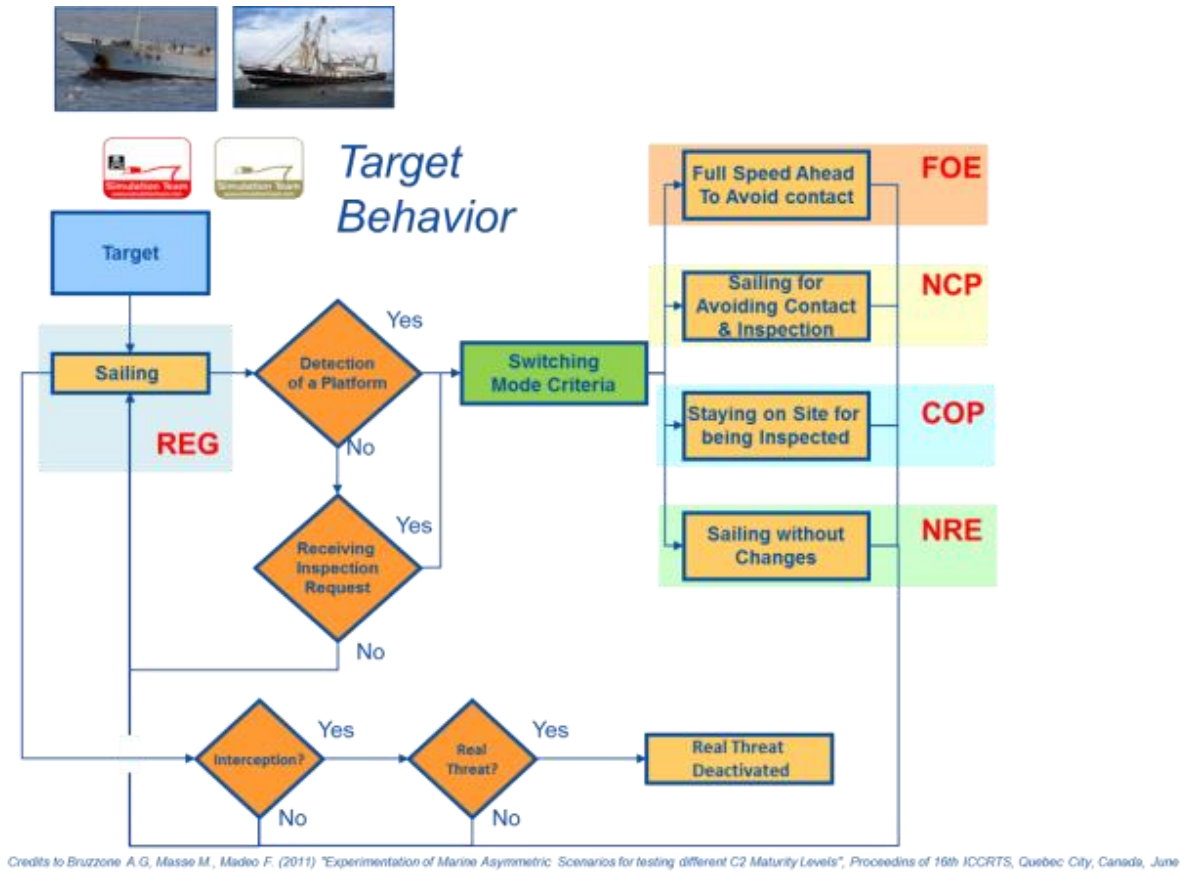


Figure 11 JAMS2 Targets Behaviour

Switching Mode Criteria is applied in the simulator to assign operation modes to threats perceiving an asset when detected or when receiving an inspection request (Figure 11).

In JAMS2 the "mode probability" of the boats depends on their nature (if pirates are on board), Current Status (e.g. REG, NRE, etc.), and Platform distance (in three levels) as shown in the explicative Table 2.

2.3 Input files

JAMS2 receives data and information about current situation from the AADSS; these data are used as simulation boundary conditions and represent the real data collected over the area (e.g. sea, wind, temperature, currents etc.) as well as information corresponding to historical data (i.e. probability of attack in a zone). The data are extracted from the maritime scenario database and transferred as files through a web service application to the JAMS2 operative workspace; these elements include, among the others, the following information:

- Planned path exploited in waypoints (CSV format)
- General Configuration (ASCII format)
- Asset basic characteristics (ASCII format)
- Candidate solution identifier (ASCII format)
- Probability of attack (Piracy Activity Group maps, PAG maps) over 20x16 cells (TIFF format)
- Weather Conditions over 20x16 cells (TIFF format)

Table 2 Target Mode Probability

Switching Mode Input			Mode Probability				
Target Nature	Current Status	Platform Distance	REG	NRE	COP	NCP	FOE
Real Threat	NCP	≤1 NM	0%	4%	1%	25%	70%
Real Threat	NCP	(1NM, 4 NM]	5%	4%	1%	60%	30%
Real Threat	NCP	>4 NM	5%	4%	1%	70%	20%

Real Threat	NRE	≤1 NM	0%	14%	1%	25%	60%
Real Threat	NRE	(1NM, 4 NM]	5%	24%	1%	50%	20%
Real Threat	NRE	>4 NM	10%	49%	1%	30%	10%
False Alarm	REG	≤1 NM	10%	10%	70%	5%	0%
False Alarm	REG	(1NM, 4 NM]	20%	15%	50%	10%	5%
False Alarm	REG	>4 NM	20%	30%	20%	25%	5%

JAMS2 goal is the evaluation of planned path robustness and flexibility, so input database and data for processing threats and assets behaviour are kept separated.

2.4 Experimentation

Experimental campaign within the JAMS2 project addresses VV&A of the simulator. Due to the strong non-linearity of the simulated system, a careful experimental design is necessary for proper verification of the stochastic influence on the results and to quantify corresponding experimental error (Kleijnen, 2007). The methodology used is the analysis of the Mean Square Pure Error (MSpE). The corresponding results allow the identification of the optimal duration of the simulation run for properly estimating the pure experimental error introduced by the stochastic factors. In this section it is proposed a preliminary analysis conducted on a subset of target functions:

- Total Covered Area
- Mean Time Elapsed Deviating from the Planned Path
- Max Time Elapsed Deviating from the Planned Path

- Patrolling Time Percentage

Patrolling Time Percentage is the percentage of time spent on the planned path with respect to the mission time; Mean and Max Time Elapsed Deviating from the Original Path are respectively mean and maximum time spent by the ship deviating from the planned path, intervening and going back on the planned path.

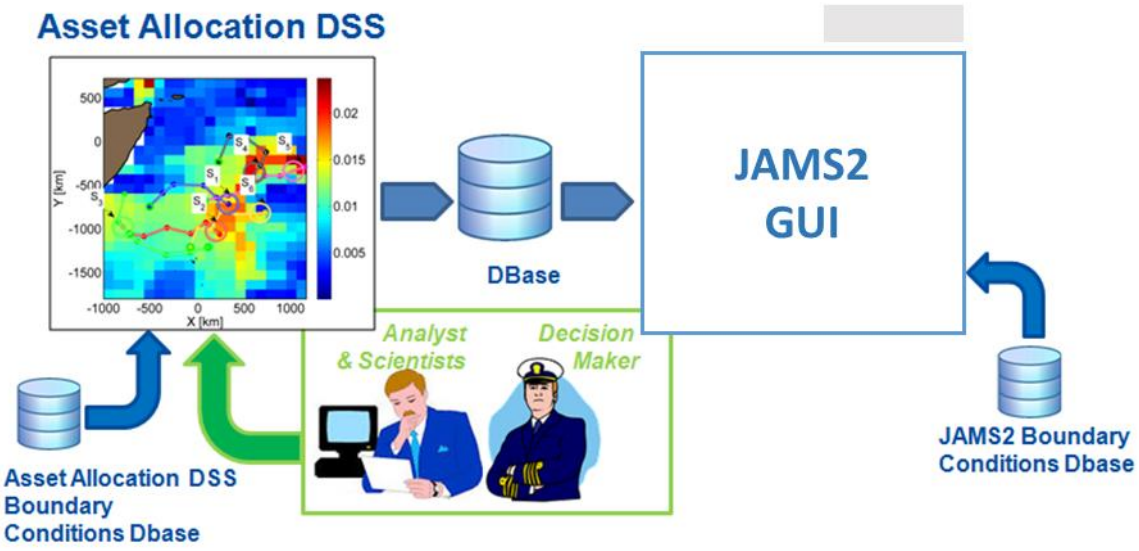


Figure 12 JAMS2 Original Configuration with Optimal Asset Allocator

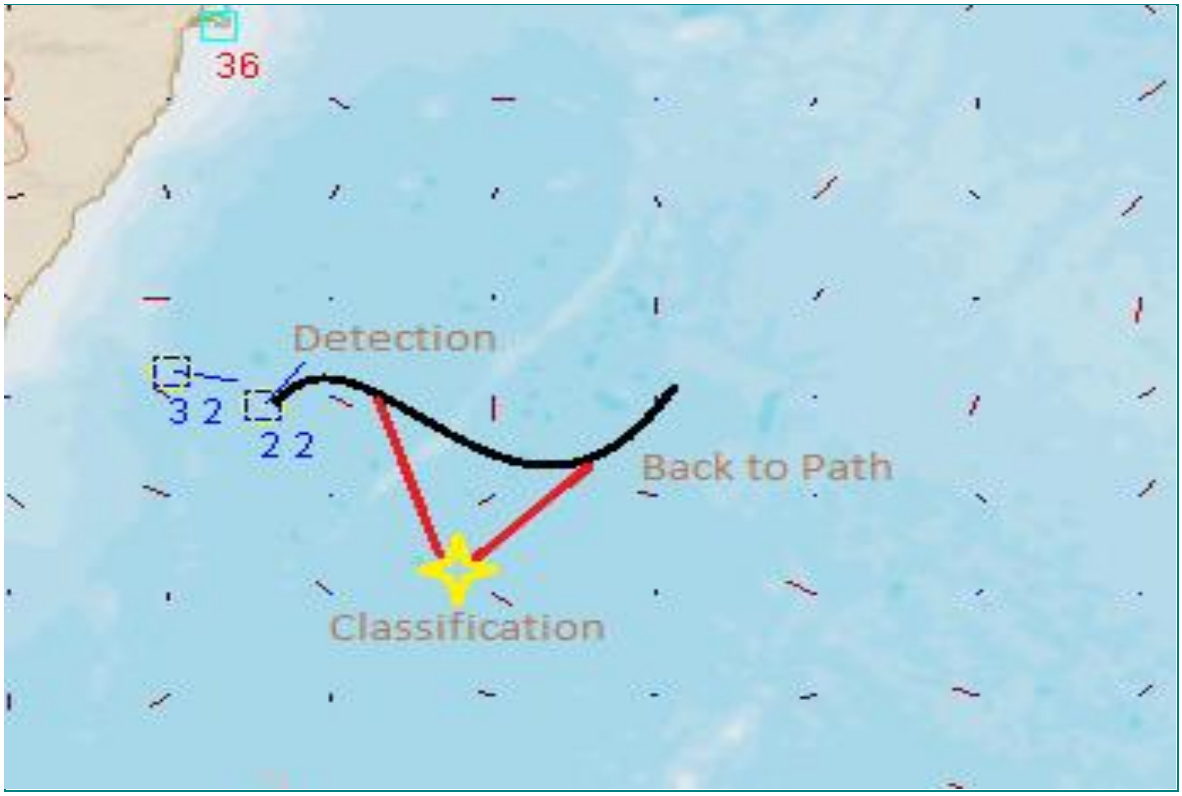


Figure 13 Asset Deviating from the Planned Path

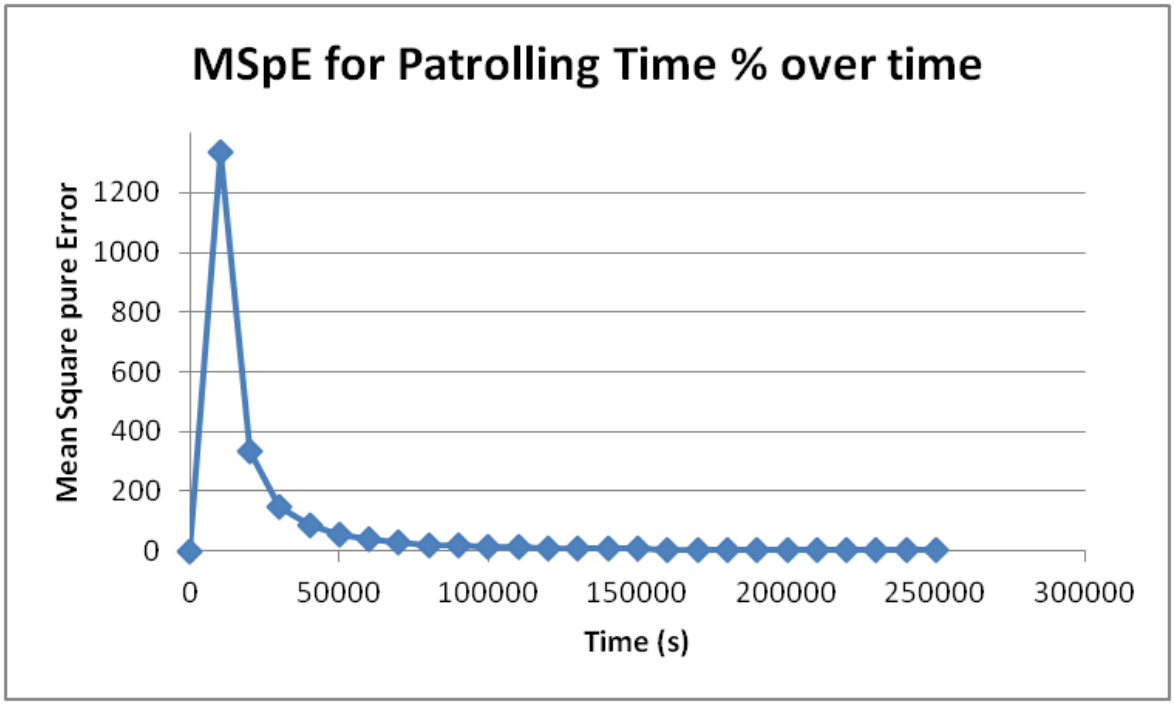
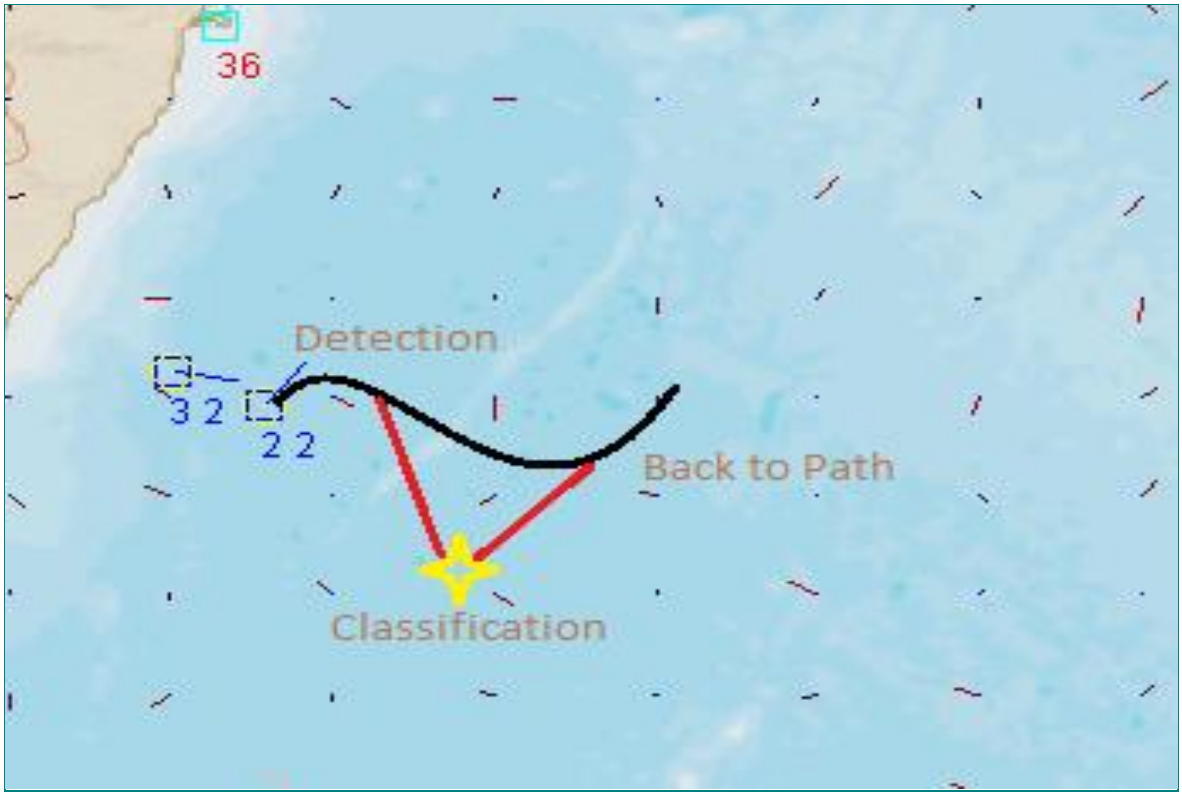


Figure 14 MSpE for Patrolling Time Percentage over time for Detection Range R1



In Figure 13 is represented the graphical representation of a ship deviating from the planned path (black line) after detecting a target.

The experimentation was conducted choosing three values of Intervention Range as input parameter: R1, R2, R3 (where R1<R2<R3); this variable corresponds to the maximum distance of a suspect target respect a vessel for activating an investigation procedure (e.g. sending UAV or USV).

For each of the three cases the experimentation was conducted with the same number of replication using the same boundary conditions. The simulation duration was set to three days for each run; JAMS results obtained in the experimental campaign represent an

important element for VV&A of the models and for evaluating robustness of AADSS algorithms.

The results obtained summarize the evolution of MSpE for each target function with respect to the simulation time and replications; for instance, Figure 8 shows Patrolling Time Percentage variance for Intervention Range R1 stabilizing within one simulation day; similar graphs are proposing the other target functions.

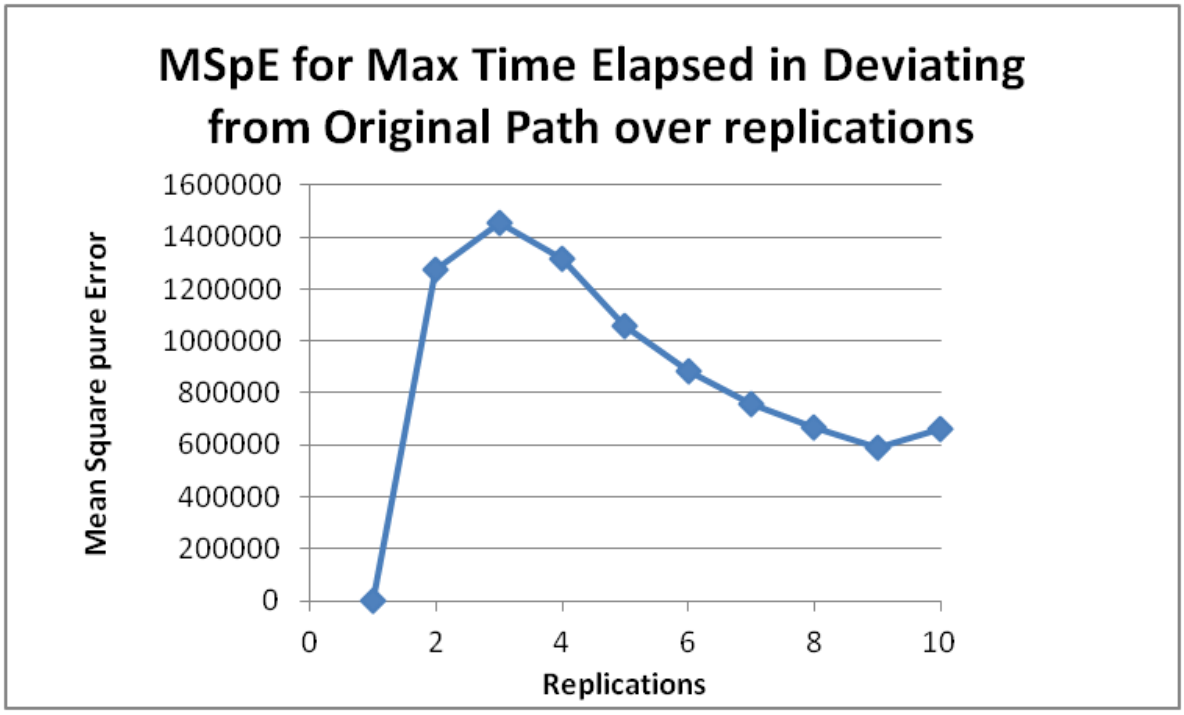


Figure 15 MSpE for Max Time Elapsed in Deviating from Original Path over replications for detection range R1

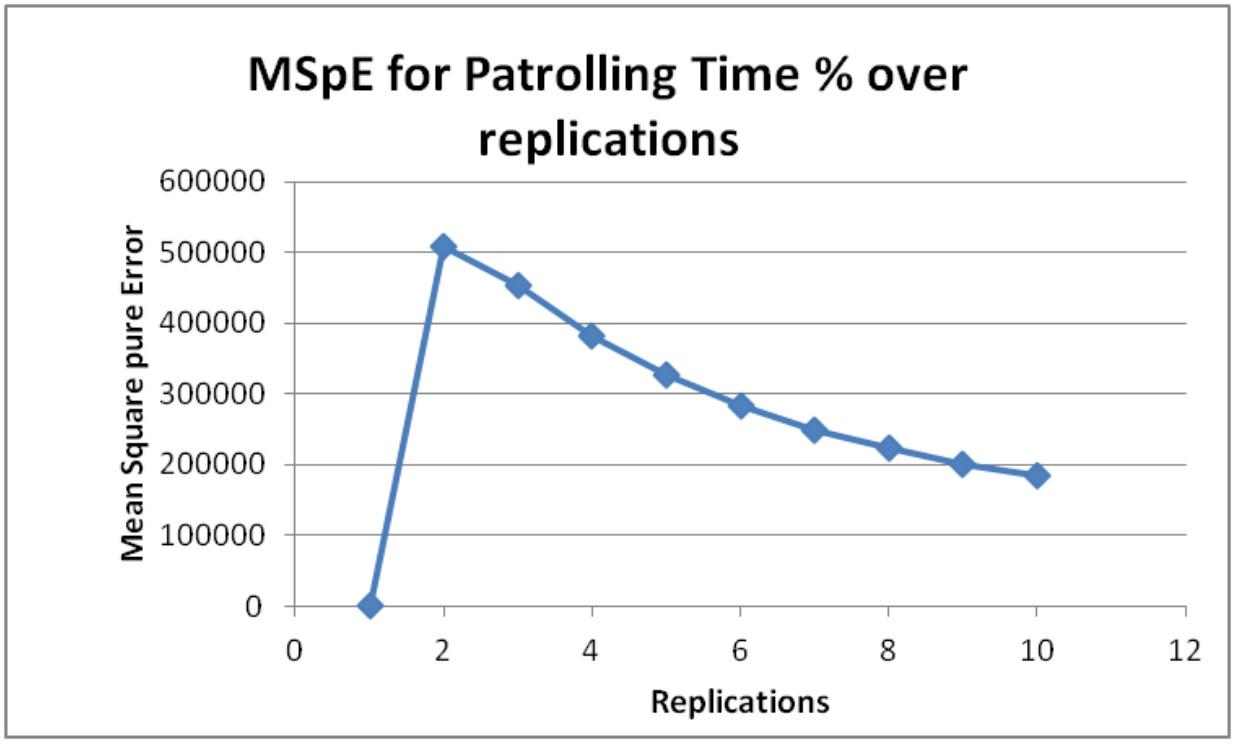


Figure 16 MSpE for Patrolling Time Percentage over replications for Detection Range R1

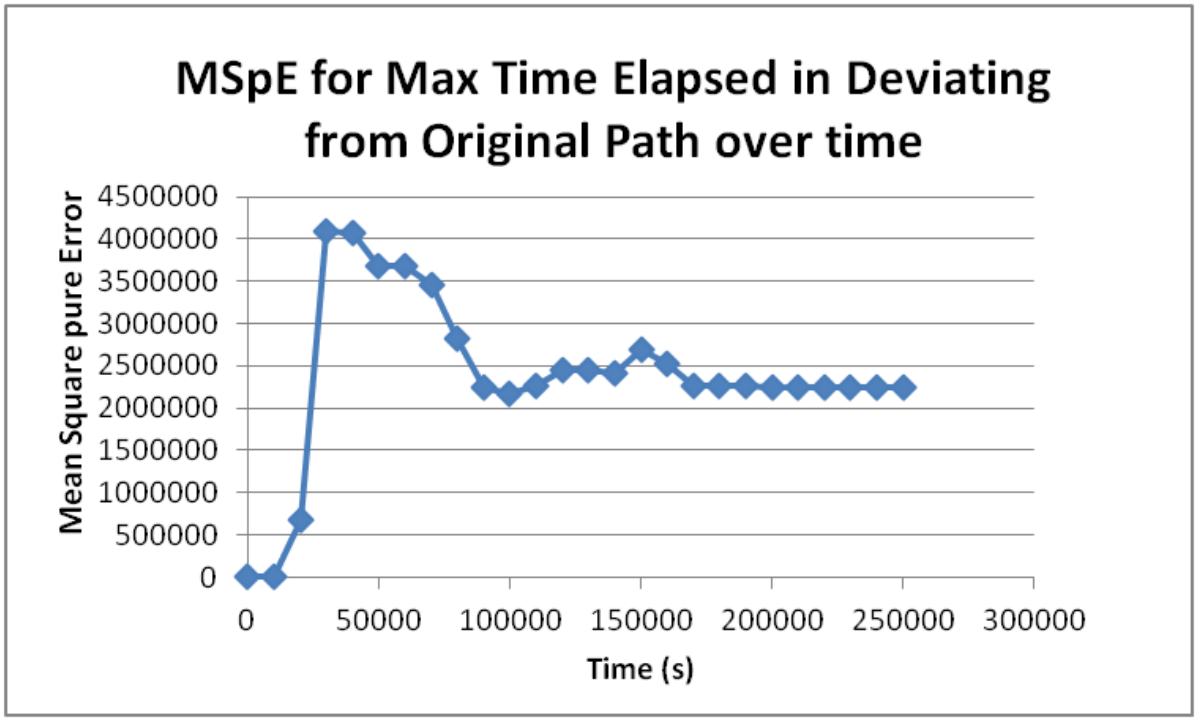


Figure 17 MSpE for Max Time Elapsed in Deviating from Original Path over time for detection range R2

Figure 17 shows the MSpE for Max Time Elapsed Deviating from the Original Path stabilizing within three days. Comparing the graphs is possible to outline a common trend for target functions changing the Intervention Range. Figure 21 shows the Max Time Elapsed in Deviating from Original Path is increasing with the Intervention Range. This means that assets spend more time investigating targets with high intervention range than with small ones. The same is observable in Figure 23.

Today the current release of the JAMS2 simulator does not include very detailed models for sensors, weapon systems and communication due to resource constraints, but pretty good Meta-models are already implemented in JAMS2 to guarantee the generalization capacity; in short it will be possible to upgrade them for further developments related to evaluating

the influence of innovative solutions or procedures in anti-piracy as already done in other cases (Bruzzone et al. 2011c).

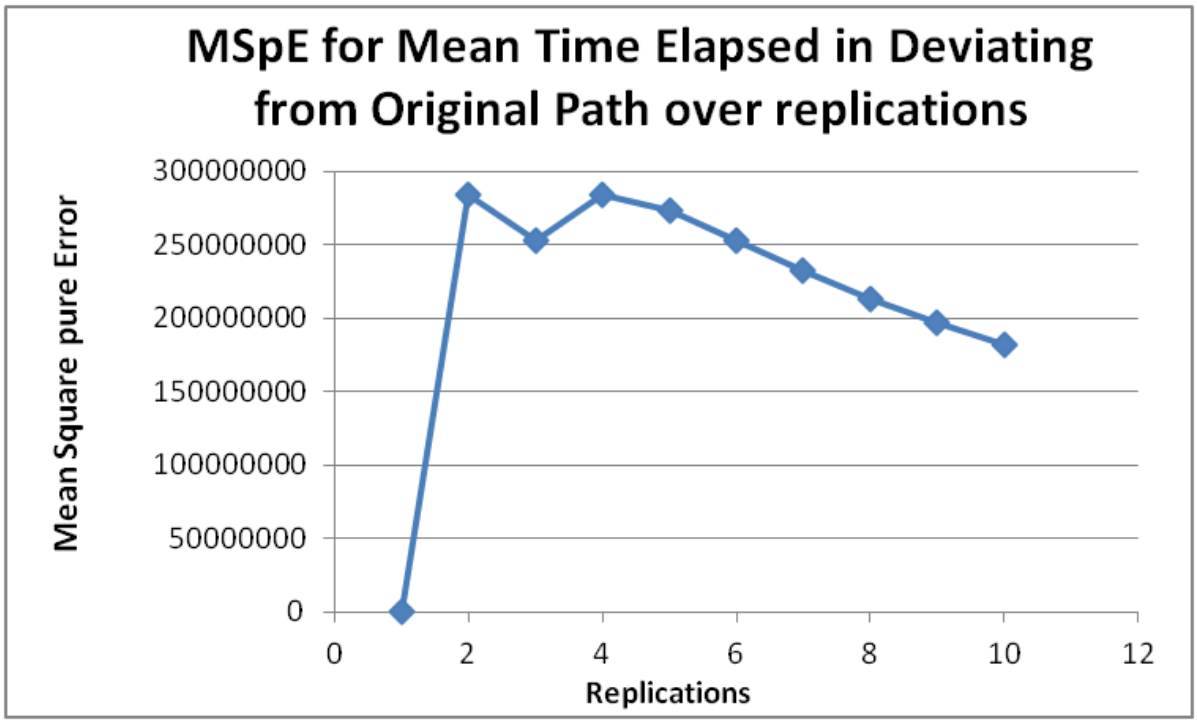


Figure 18 MSpE for Mean Time Elapsed in Deviating from Original Path over replications for detection range R3

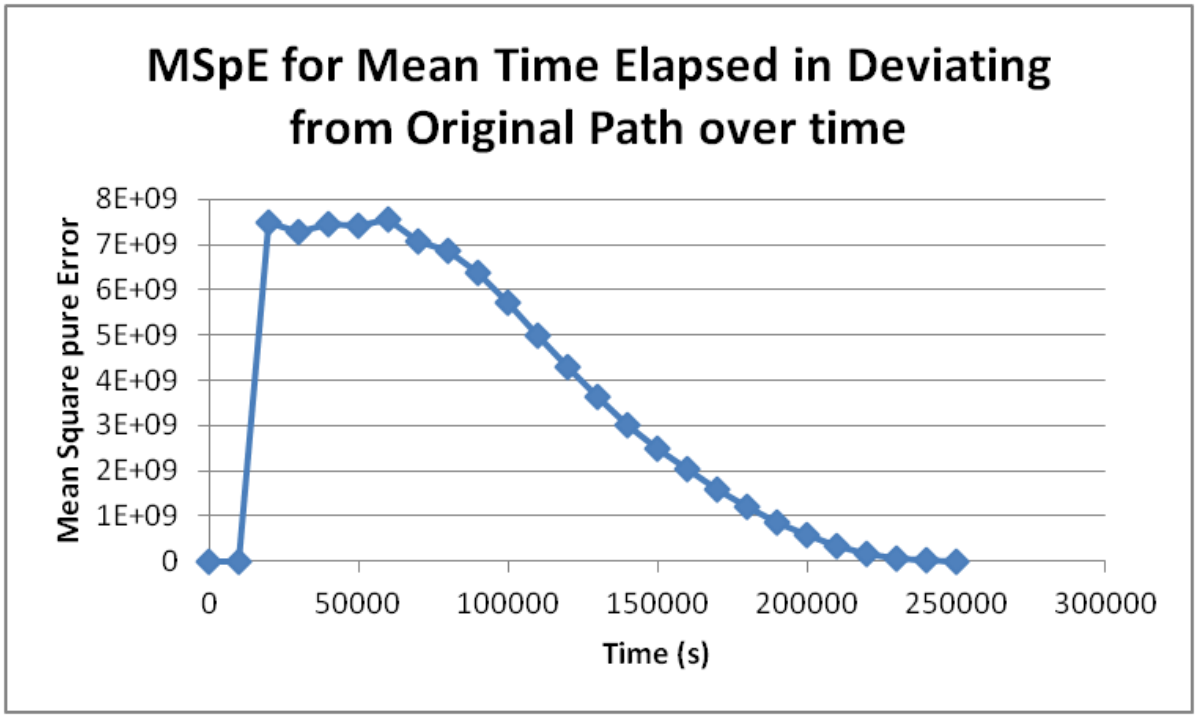


Figure 19 MSpE for Mean Time Elapsed in Deviating from Original Path over time for detection range R1

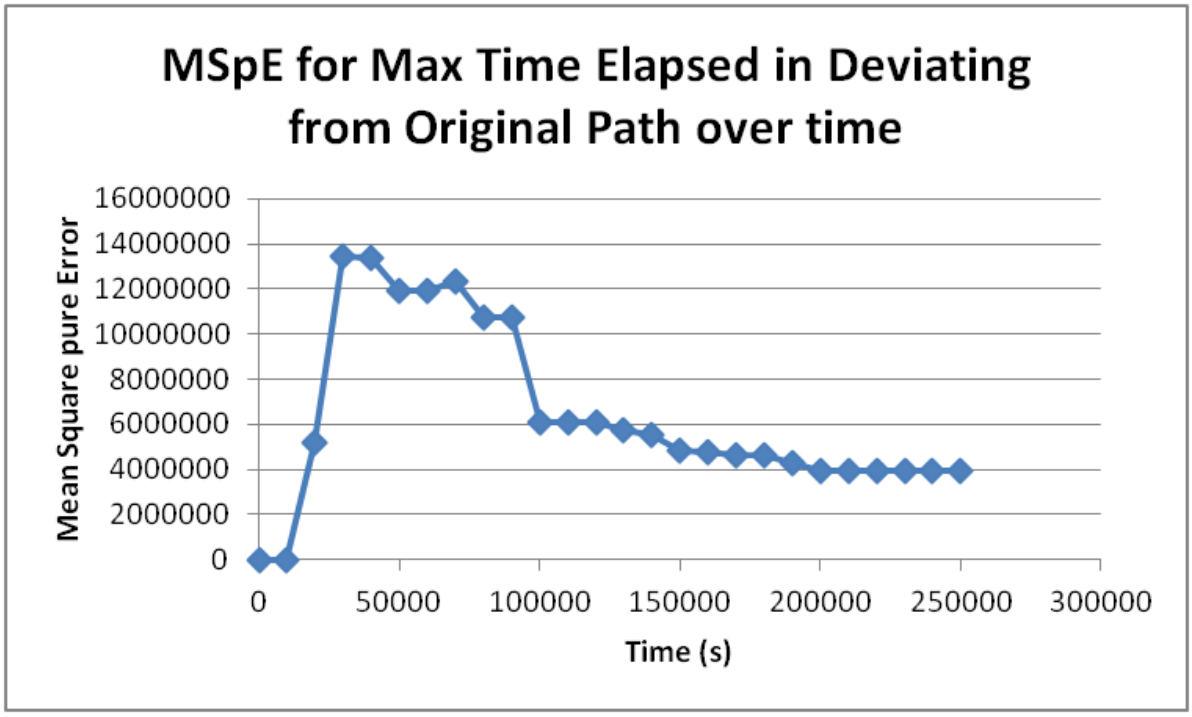


Figure 20 MSpE for Max Time Elapsed in Deviating from Original Path over time for detection range R3

For the same reason, currently a detailed Recognized Maritime Picture (RPM) and a traffic simulator reproducing all the targets in the area are not included; indeed in JAMS2 targets are generated based on a specific risk map for the simulation derived from the ones used in the AADSS.

This solution is considered satisfactory for current purposes, but it does not allow evaluation of the resilience to false alarms generated by analysing the RPM such as the deviating course of a boat toward a cargo ship (corresponding to generating suspects on its behaviour).

These kind of behavioural data fusion are currently limited, contrary to simulators such as PANOPEA, and it is advisable to consider future extensions of the current model.

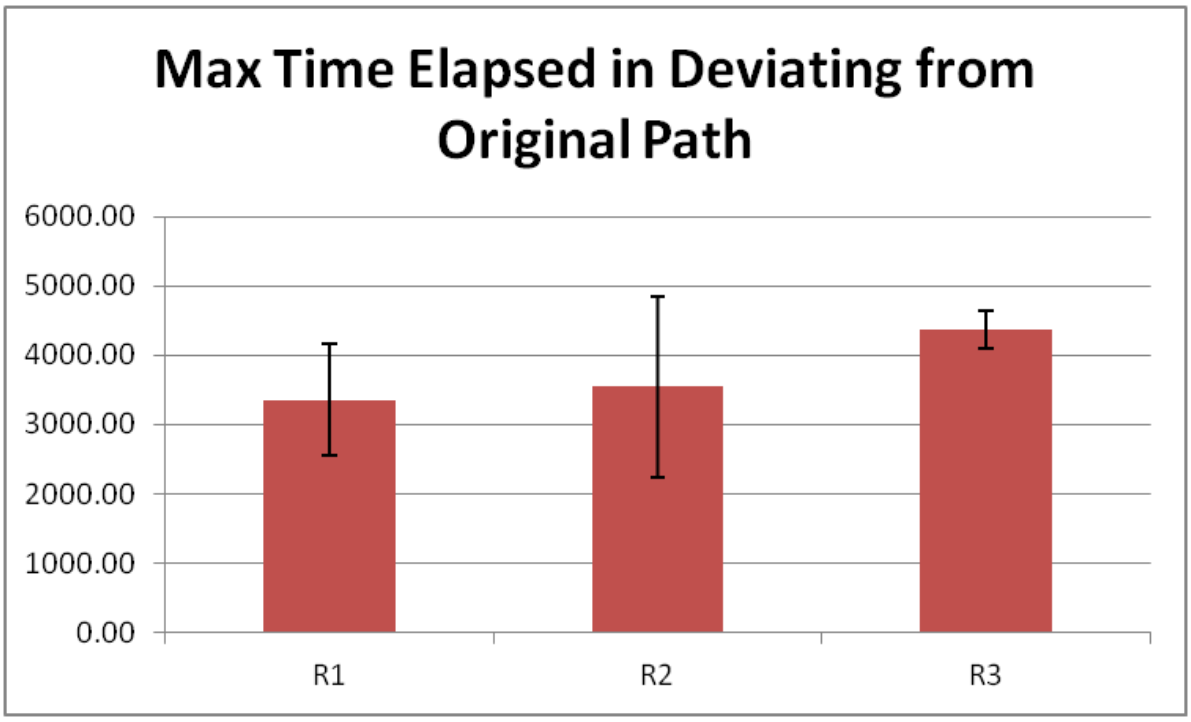


Figure 21 Average Max Time Elapsed in Deviating from Original Path over Intervention Range

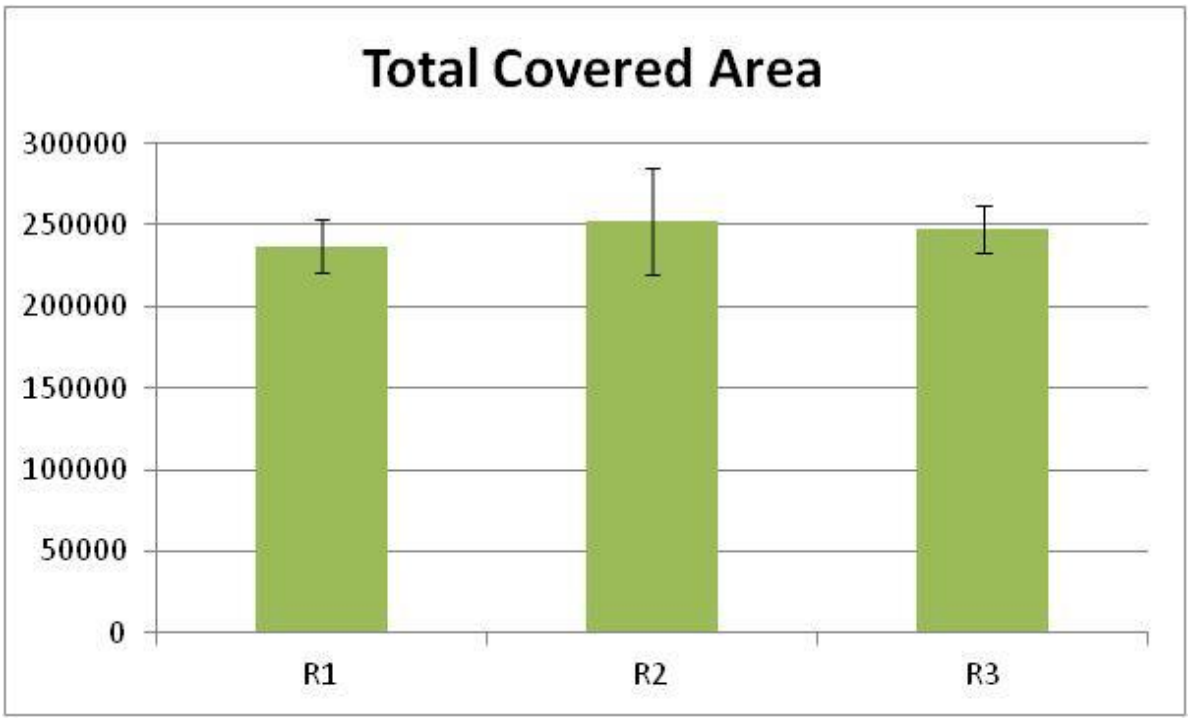


Figure 22 Average Total Covered Area over Intervention Range

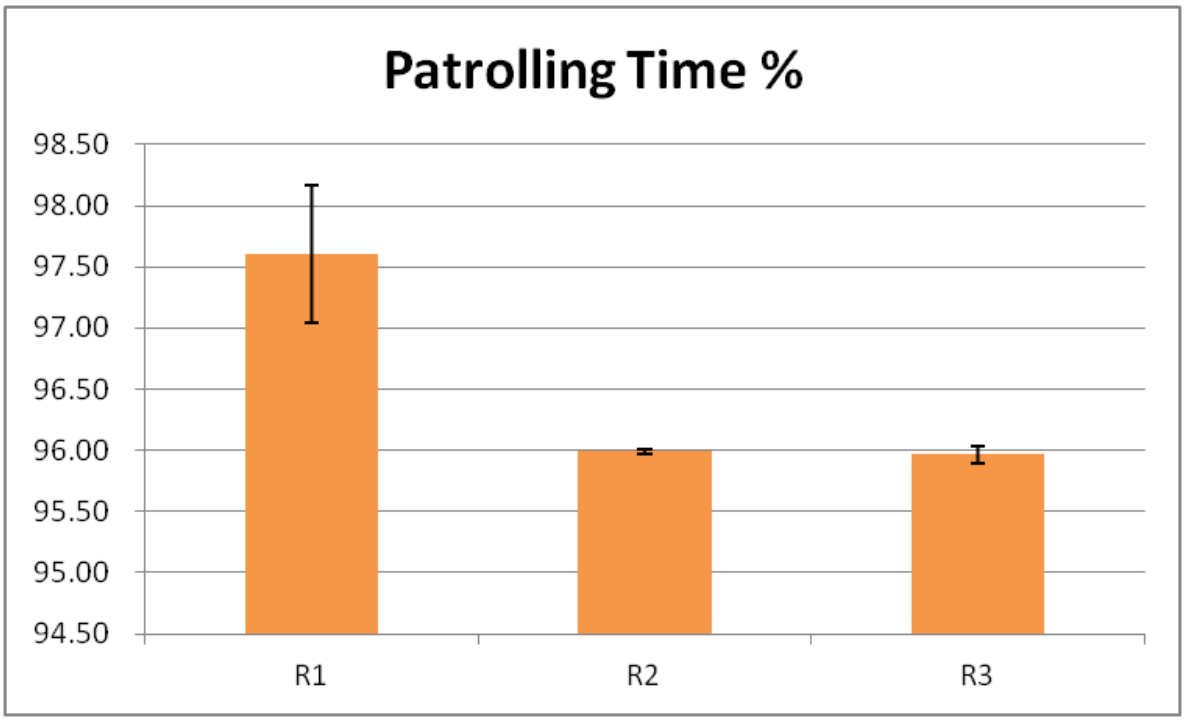


Figure 23 Average Patrolling Time Percentage over Intervention Range

On the other side, the versatility of the JAMS2 architecture allow for the implementation of new type of assets to address different scenarios for asymmetric warfare; the same implementation could be carried out for deployable resources to simulate more complex scenarios.

The Switching Mode capability model guarantees an easy way to redefine the tables and the author is evaluating the possibility to adopt Fuzzy Allocation Matrices to determine threats operation mode.

Another important potential of the current simulator is the possibility to develop a federation involving other existing simulators for supporting training and education. An example of such kind of federation is shown in Figure 24.

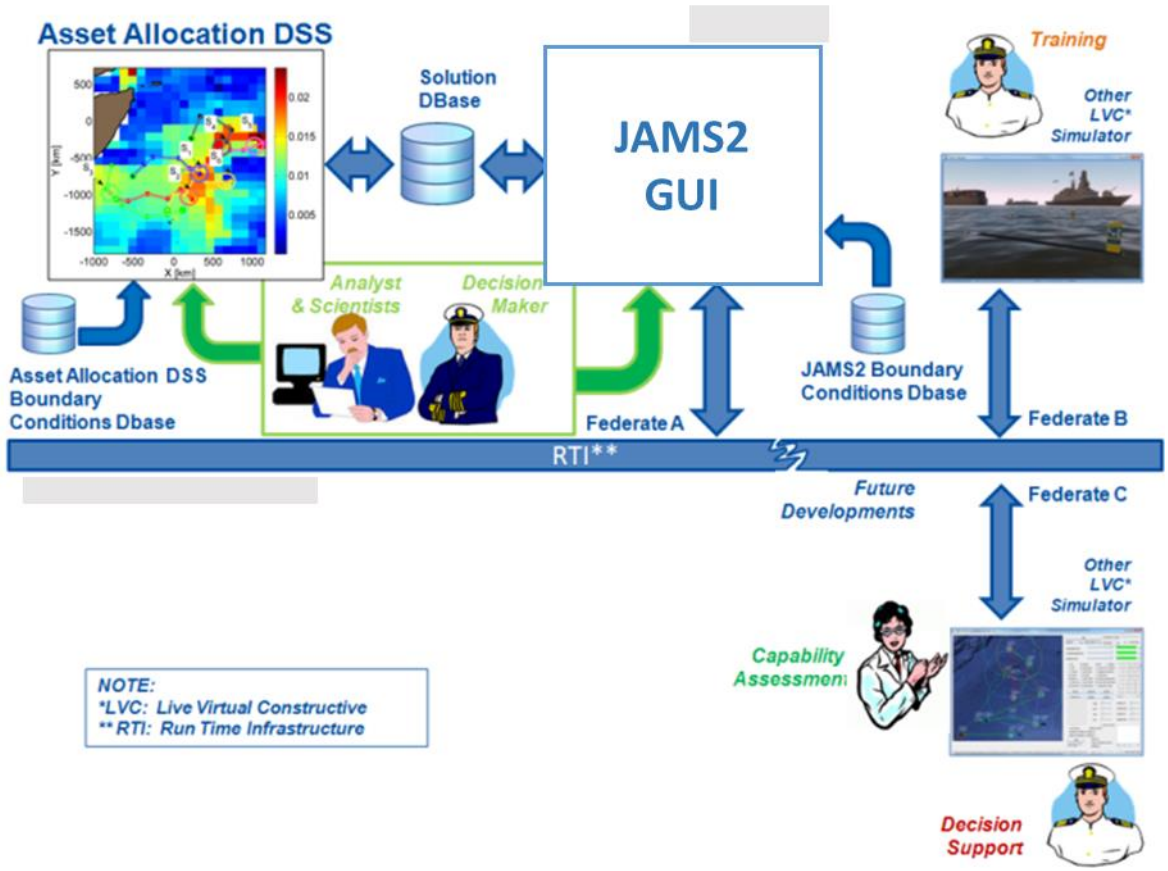


Figure 24 Example of a Federation with JAMS2

2.5 Outcomes

This section presents an example of the study for the development of a simulation framework integrated with planning aids as support for patrolling routing optimization in anti-piracy operations; the flexible architecture used allows to achieve interesting conclusions even with limited resources within short time; in addition, there is a big potential in further developing these models to create interoperable federation open for integrating other elements including real C2. In this case it could be interesting to create decision support systems integrating

artificial intelligence methodologies and simulation within dynamic and reliable decision support systems.

Last, but not least the use of simulation in this context provides a strategic advantage in creating educational and training aids to promote the use of such innovative DSS among the user community and in improving the planning capability to face complex asymmetric scenarios. Indeed, the author suggests using JAMS2 and the Optimal Asset Allocator for training and education purposes for decision makers; this is an important added value for this system in addition to its capability to be used as virtual test bed for Decision Support Systems.

3 Critical Infrastructure Protection

Critical Infrastructure Protection is a rising issue in today world; considering that most of the population lives on coastal area it is not surprising the fact that several of these infrastructures, e.g. ports, piping, cables, off-shore and coastal on shore plants, are located within marine scenario and are being more and more targeted by asymmetric threats. Employing Autonomous Assets allows to drastically reduce the protection costs but requires to design new solutions (Bruzzone et al. 2018c).

This section gives special attention to off-shore platforms investigating the opportunity to improve threat assessment by innovative solutions.

The Agent Driven stochastic simulation is adopted for reproducing a combined used of autonomous and traditional assets devoted to identify threats as well as the possibility to use it for training Unmanned Aerial Vehicles (UAV) pilots. The author presents the results of the experimental campaign obtained on a test population of unskilled operators to evaluate the possibility to diffuse the use of such approach without requiring very highly qualified expertise.

3.1 Case Study

As said before, the geopolitical situation and the technological evolution is emphasizing the potential impact on critical infrastructure, for several reasons: general presence of heavy threats in terms of security related to terrorist organizations, vulnerability of existing critical infrastructures to easily accessible technologies operating on different layers, such as IED

(Improvised Explosive Device), cyber-attacks, malicious autonomous systems (Abrahams et al. 2005). The technology evolution is even further emphasizing these elements because is becoming more and more common to have critical infrastructures that are remotely operated, such as happens in energy sector, with many renewable energy solutions geographically widespread and lightly supervised and protected (e.g. wind farms).

Another fact is the great need of energy for human societies (McKercher et al. 2004, Mastrangelo 2005) that promotes the growth of natural gas consumption and resulting risks connected with these facilities that are sensitive to terrorist attacks (e.g. NLG terminals). All these considerations highlight the problem of critical infrastructure protection (Bruzzone et al. 2013a). One factor that is strongly affecting countermeasures effectiveness is the sustainability in terms of reliability, operational costs, efficiency etc. For these reasons, it is evident that autonomous systems represent on one hand a potential threat and on the other an interesting resource for protecting critical infrastructures (Hill 1996, Hudson 1999, Mevassvik et al. 2001, Bruzzone et al. 2011a). It is worth to mention that actually, the autonomous solutions do not cover completely the mission spectrum; often protection, patrolling, block operations are expected to be carried out by traditional assets or at least in co-operation with them. This means that it is necessary to integrate these systems to evaluate the best configuration and even to identify how to cover the different spaces domains: cyber space, space, air, land, sea surface and underwater (Bruzzone 2013, Bruzzone et al. 2013b). An interesting observation is that many critical infrastructures are located in coastal areas

due to the fact that ocean traffic supports most of logistics and connection and that the majority of the population live on urbanized coastal town.

3.2 Purpose of the Simulation

The author proposes an approach that integrates AI algorithms for face recognitions with sensors mounted on rotary wings UAV as support for protecting offshore platforms. In this case the simulation is devoted both to understand the operative advantage of a rotary wing UAV employed on off-shore platform and to provide a test-bed to train UAV operator performing recognition activities in a hostile environment facing unconventional targets.

The simulator proposed for this case is titled SO2UCI (Simulation for Off Shore, On Shore & Underwater Critical Infrastructure) and it has been developed by the author within the Simulation Team; SO2UCI is a simulation able to support training on protecting Off-Shore Platforms (e.g. oil rig, gas rig), On-Shore Critical Infrastructures (e.g. ports, power plants, refineries, desalinators) and Underwater Critical Infrastructures (e.g. cables, pipelines) from Asymmetric Threats using conventional assets and autonomous systems (e.g. RHIB, Helicopters, Sensors, UAV, USV, AUV, Gliders, etc.). The simulator is interoperable by using HLA (High Level Architecture) and supports integration with real equipment as well as with other simulators and solutions as the SPIDER. SO2UCI integrates scenarios for training the use of specific sensors on rotary wing UAV to discriminate suspect boats invading the perimeter of Oil Rig (e.g. face recognition, thermal camera, etc.). The models have been verified by applying VV&A Procedures (Blaci et al. 1996).

In the proposed experimentation the user of the simulator is the UAV Operator. The control system of the UAV is very basic and adopts simple game interface; indeed this is due to the experimental nature of the project, but also to the consideration that most of future operators could be more familiar with this solution. Further development might possibly include the setting of a more specific control system and integrated framework with other protection systems.

The user main goal is to pilot the rotary wing UAV close enough to the boats in order to activate recognition sensors, entering their range and within a specific relative position to catch the crew face. The user has to remain within the sensor range until sensors data acquisition process is over; the process is supported by information and alert provided by speakers to the boat from the UAV; it is evident that for many reasons non cooperative behaviour could be expected and could lead to alert just based on additional evidence of suspect behaviours. The purpose of the experimental campaign, on the other hand, is both the evaluation of the impact of simulation for training purposes and the influence of augmented information provided by the simulation to pilots such as enabling the visibility of sensors range and of the required profile to successfully approach a suspect boat.

3.3 Scenario and Model Description

This section describes a scenario for training operators in controlling a remotely operated patrolling asset for an off-shore critical infrastructure protection. The scenario is set in deep water and the entities involved are:

- A Semi-Submersible platform
- Piping Infrastructures
- Small-Medium Size Boats
- Rotary Wing UAV (Umanned Autonomous Vehicle) and its Sensors
- Autonomous Underwater Vehicles

In facts the use of Autonomous Underwater Vehicles (AUV) in this testing is limited, but in other cases its use would cover submerged threats and it is maintained. The simulation adopts High Level Architecture to support interoperability and could be connected with other simulators.

The simulator reproduces the physics of the entities and their control and actions. Sophisticated Intelligent Agents developed by Simulation Team are devoted to drive the entities and to reproduce behavioural model of small-medium size boats controlling their routing and speed (Bruzzone et al. 2011b).

The models of the sensors embedded in the Drone are devoted to perform crew face recognition and overall boat identification and classification in order to finalize the threat assessment based on these aspects and the boat behaviour analysis.

During the Simulation it is possible to present an augmented reality tool where the sensors range and boat approach profile are proposed by a 3D visible volume, displayed around the fore part of the boats to help the UAV operator (Figure 25). Furthermore, the simulator gives the user the possibility to visualize, at run-time, the percentage of completion of the sensors acquiring process computed as in the equation below:

$$Completion\ \% = \frac{Time\ inside\ Working\ Range}{Nominal\ Working\ Time} \cdot 100$$

The Acquisition Process is cancelled in case the pilot exits the sensor range or adopt improper flight profiles before acquisition completion and restarts when entering the range again; the computation is referred to the single specific boat in the vicinity of the drone. Once face recognition is completed the Simulator provides a report about the time spent in performing the activity and an overall evaluation. In general, the test is considered failed when the drone impacts the water or is damaged due to a crash.

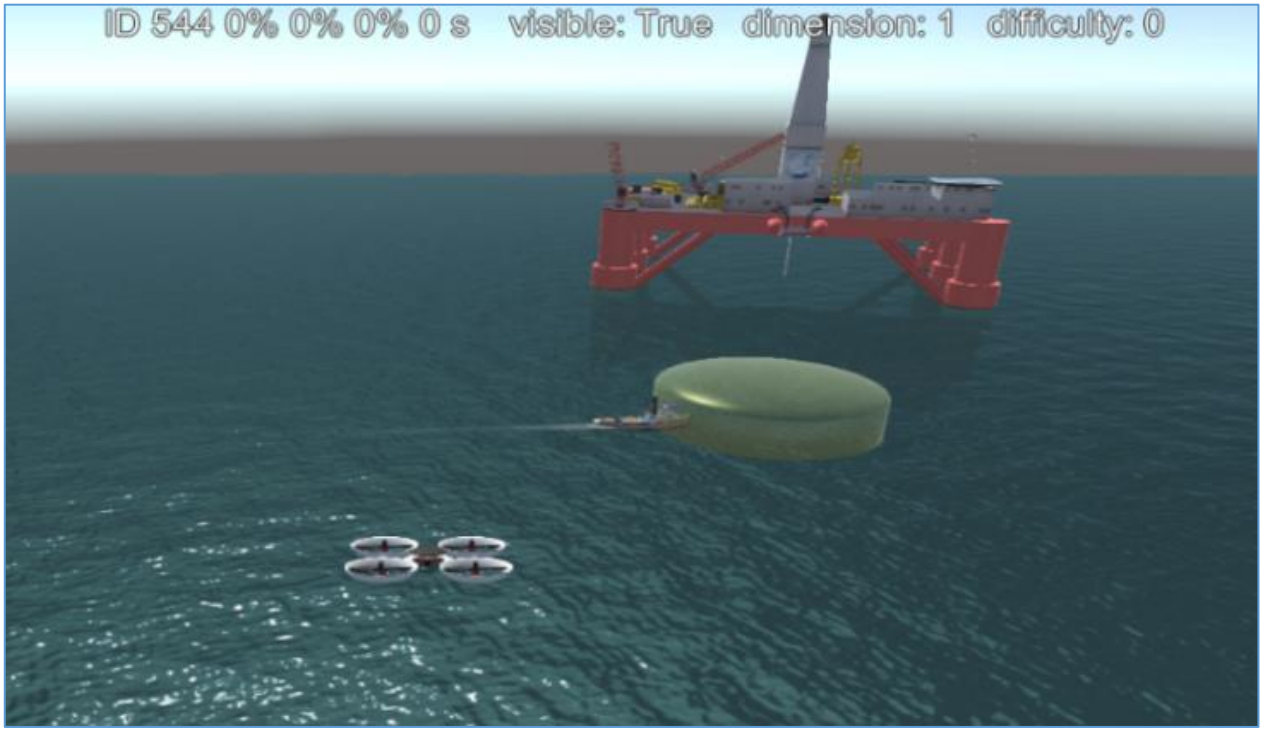


Figure 25 Simulation settings on screen top

Through the User Interface it is possible to act on the following settings:

- Augmented Reality for Sensor Range and Profile:

    - Non-Visible,
    - Visible Range,
- Dimension of the Sensor Range:
    - Small Range,
    - Medium Range,
- Difficulty Level:
    - Boats keep almost constant heading and adopt cooperative behaviour,
    - Boats manoeuvre to evade the drone and adopt not cooperative behaviour.

3.4 Experimental Campaign

The experimental campaign has been performed on a test population of 12 operators. The operator used were unskilled people and students, with limited or no experience in operating UAV; this approach was devoted to investigate the possibility to quickly train this kind of user to operate such procedures; it is evident that the sampling is very reduced and the results are limited and specific of the proposed case, so no general considerations could be finalized. However the study provide interesting considerations that actually the author used to conduct further development and testing. In the experimentation the operators performed 6 attempts each with constant difficulty and Sensor Range. The experimental campaign is designed to evaluate the influence of two target functions: Number of Successful Recognitions and Time to Accomplish Recognition respect the following independent variable:

- Sensor Range

- Augmented Evidence of Sensor Range
- Difficulty level

In the following each target function is analysed.

3.4.1 Number of Successful Recognition

From the analysis of experimental simulation data, it is interesting to notice a higher number of successful recognitions for smaller Sensor Ranges. The reason behind this trend is the increased operator accuracy during the experimental tests.

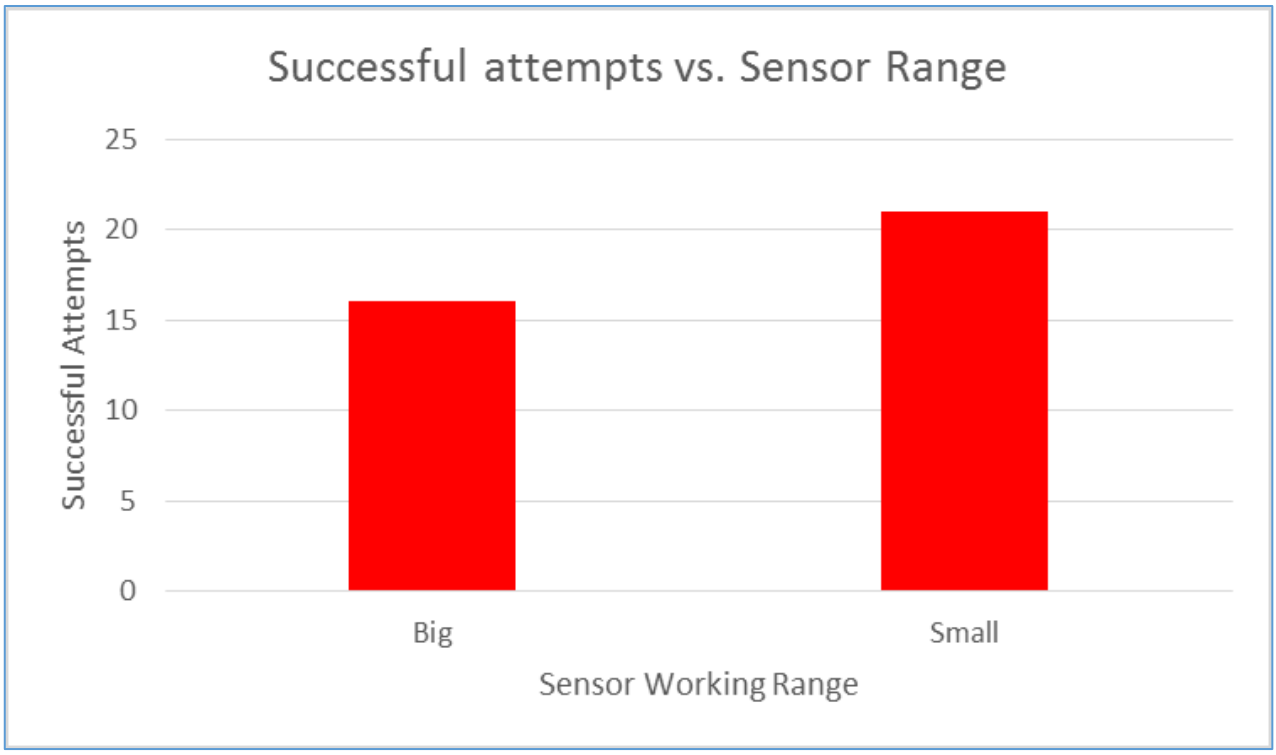


Figure 26 Successful Attempts vs. Sensor Range

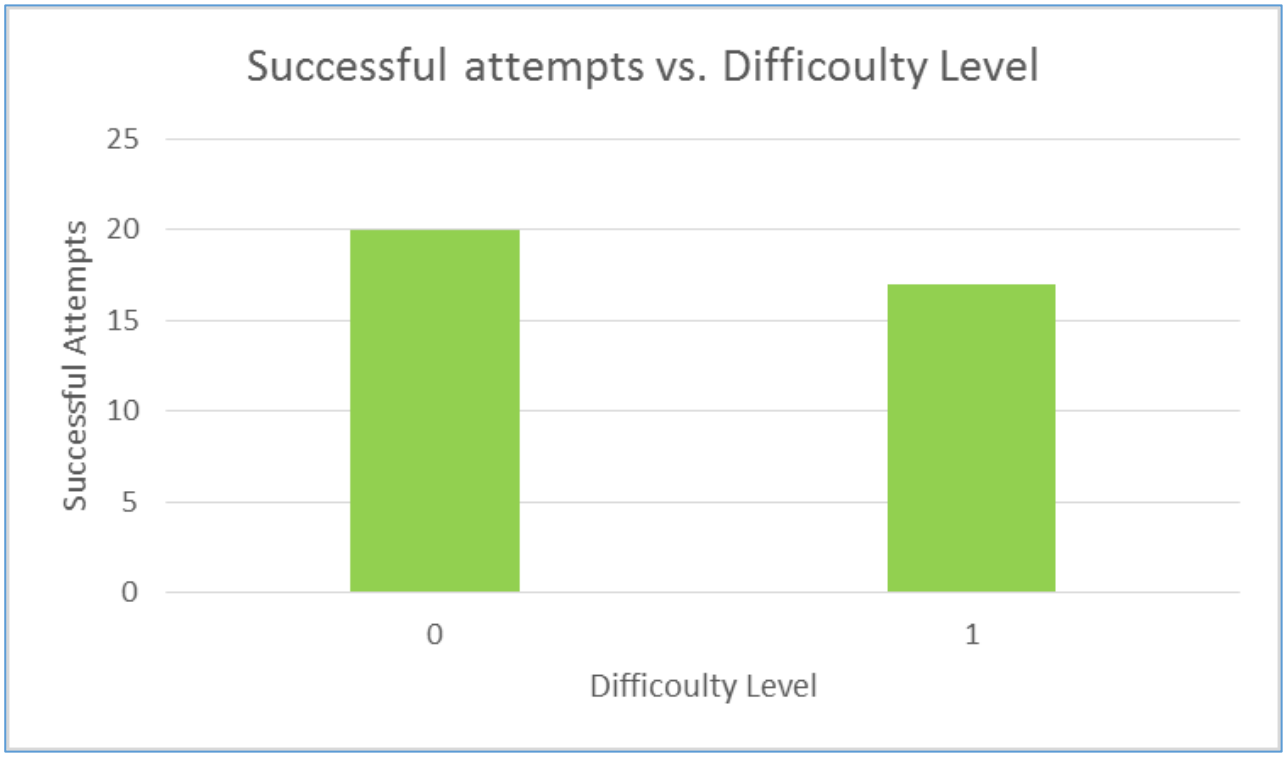


Figure 27 Successful Attempts vs. Difficulty Level

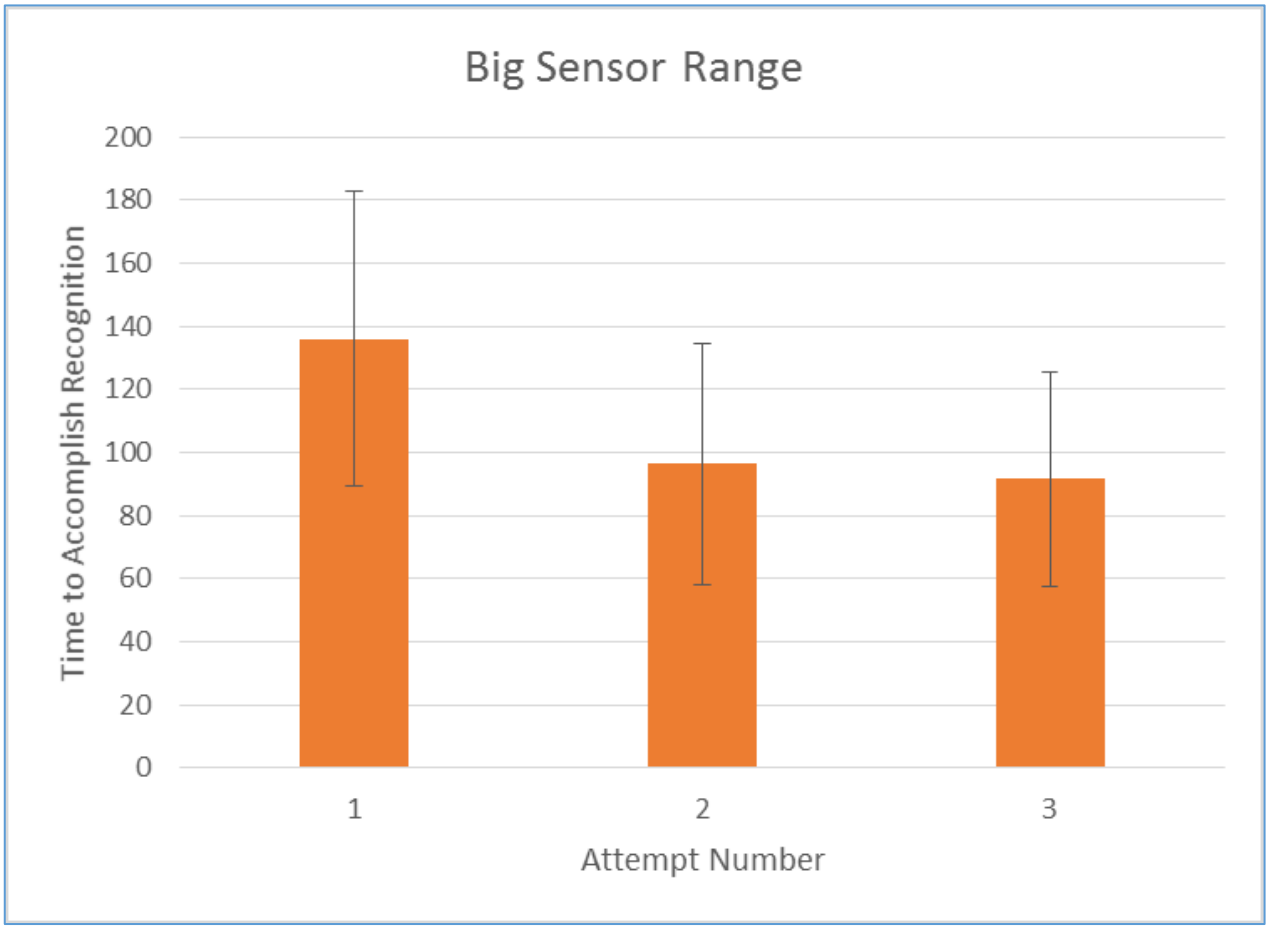


Figure 28 Time to Accomplish Recognition vs. Attempts

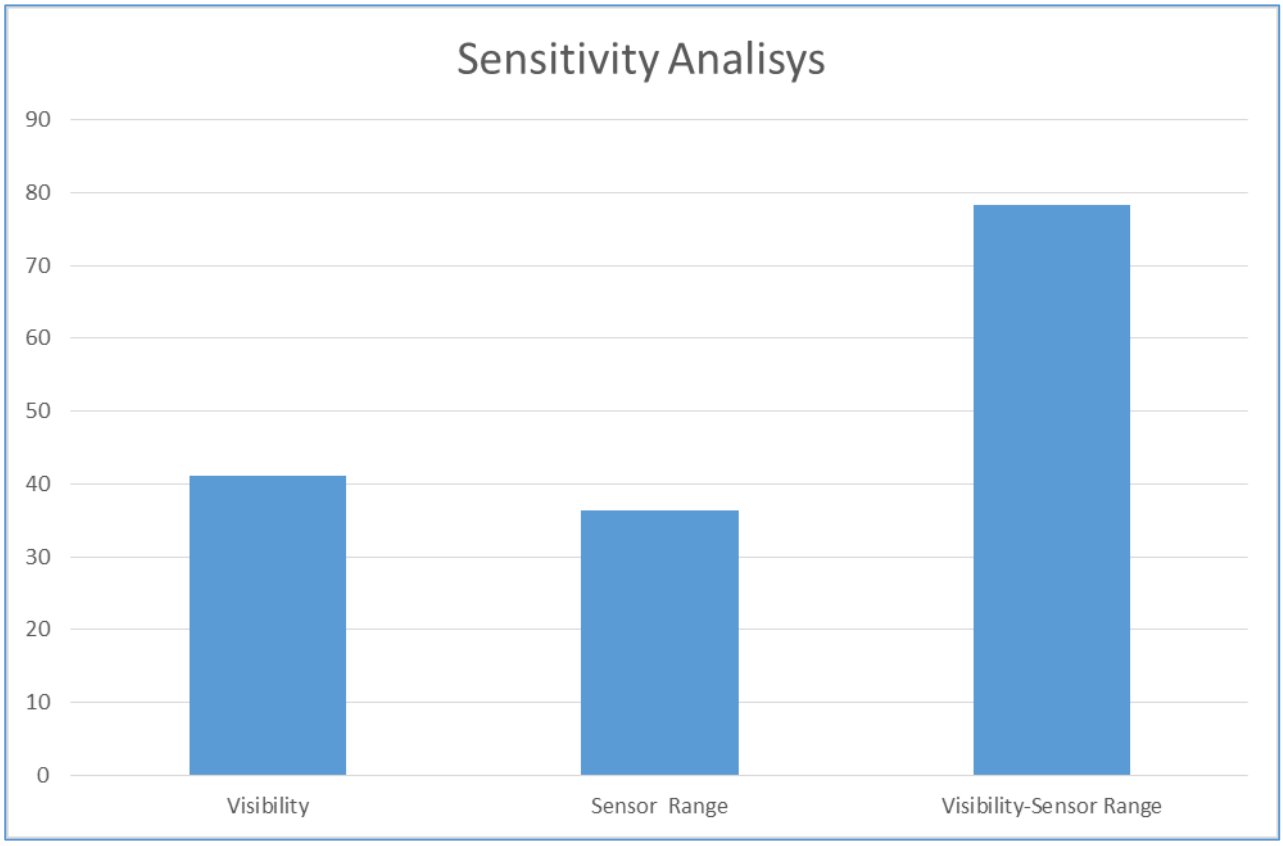


Figure 29 Influence of Visibility and Sensor Range dimension on Time to accomplish the mission

The Difficulty Level is another important aspect; in deed as expected, by increasing the not cooperative attitude of the boat to evade drone controls, the success rate of the UAV operator decreases.

3.4.2 **Average Time to Accomplish Recognition**

UAV operator performance has been evaluated in terms of time required to accomplish the first successful recognition in the scenario. The analysis of the experimental simulation data shows a positive reduction of the average time required to recognize the target over the different attempts. This result is significant even though the relative confidence band is

pretty wide; the reason behind the amplitude of the confidence band is to be found in the heterogeneous nature of the UAV operator population involved in the testing campaign, indeed some of them were keener on using serious games and were better experienced with the HMI (Human Machine Interface) than others.

The Sensitivity analysis on Time to Accomplish Recognitions, shown in the Figure 29, highlights the positive influence of the Augmented Evidence of Sensor Range; indeed, the average time required to perform recognitions improves when the Evidence of the Sensor Range is visible to the UAV operator through an augmented representation while flying.

The same considerations apply to Sensor Range size, in other words the higher the sensor range, the lower the average time to accomplish recognition. From the same figure it is possible to notice the influence of the combination of the two parameters, so to say, users provided with visible sensor range, needs less time to complete the mission if drone sensor range is high.

The experimental campaign has been performed using SPIDER (Simulation Practical Immersive Dynamic Environment for Reengineering) Interactive CAVE (Cave Automatic Virtual Environment) developed by Simulation Team. The SPIDER intended use is to support Live Virtual Constructive Simulations and even Augmented and Virtual Reality for single users or for multiple users for immersive and collaborative use of simulators (Figure 30).

3.5 Outcomes

The experimental campaign obtained on the test population shows the effectiveness of simulation both for training drones operators in using such unconventional asset to perform strategic tasks such as critical infrastructure patrolling and to evaluate the impact of additional information provided to operators during flights.

It is worth to notice, from experimental data, how the size of the sensor range have a negative impact on the number of success while it has a positive impact on the time to accomplish recognition; the operator of the drone with smaller sensor range configuration results often more careful, paying more attention to accomplish recognition, successfully completing more missions, but spending quite some time; on the other hand, the operator flying with large range configuration is often more proactive, failing more attempts, but resulting faster (in average) when succeeding.

The positives results obtained during the testing campaign show the potential use of this simulation as training tool as well as means of evaluating the effectiveness of employing an autonomous system in such a complex scenario.

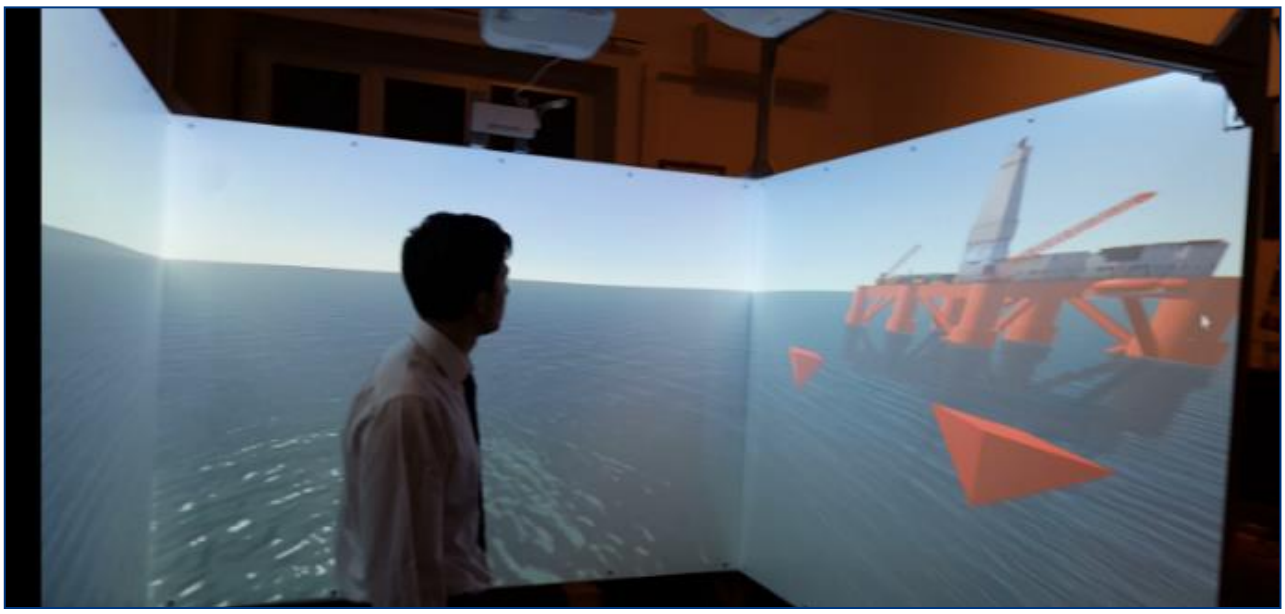


Figure 30 Testing facility, the SPIDER

4 Virtual and Augmented Reality enabling services on distributed assets

An industrial application the author has been involved during the Ph.D. has been on the application of Augmented and Virtual Reality (AR/VR) techniques for investigating how to support the implementation of distributed assets in everyday life.

The evolution of Augment and Virtual Reality is enabling new solutions. This research addresses creation of applications to support service and maintenance of distributed systems. Indeed, this approach could be applied to devices provided as service for industrial and individual use and could introduce new capabilities in terms of training for operators, control and remote service support. The research presents a case study devoted to lead the introduction of these innovative solutions in industrial and health care system. The author proposes for this research the use of the innovative MS2G paradigm (Modeling, Interoperable Simulation & Serious Games) that integrates M&S (Modeling and Simulation) and Serious Games (Bruzzone et al. 2014). Indeed in our case the combined use of AR and VR strongly benefits of this new paradigm.

Different kind of equipment and systems are extensively outsourced in Industry as well as in Public Sector. One of major aims promoting the diffusion of this approach is related to the possibility to simplify the management and to concentrate on the core activities by outsourcing the other elements affecting the processes. In addition to this aspect, outsourcing services is expected to guarantee fixed costs and to keep quality under control from sponsor

point of view. The basic idea is that the external companies taking care of the outsourcing become specialized on these service and evolve to critical masses able to provide the new services at a competitive costs; basic good examples are cleaning services, energy, gas, etc. Indeed, even if this approach is currently growing in real life business, it is evident that the new technologies are enabling new opportunities for outsourcing being able to address and solve specific challenges (e.g. remote control).

In particular, while dealing with outsourcing related to provide and operate (or guarantee operations) of distributed systems and equipment, the tracking, health management and maintenance of these elements becomes a pretty crucial factor. As matter of facts, the final customers are very interested to the reliability of the systems, but being distributed such activities could be challenging and could require specific, innovative approaches. In facts, these aspects were very well addressed in ICT sector, where most of all the new hardware are remotely monitored and specific updates and maintenance procedure are performed through distributed service (e.g. mobile phones, servers, etc.).

The developments of the IoT (Internet of Things) is further reinforcing this capability and provides new solutions to integrate distributed systems and components in networks; within this architecture it could be possible to develop innovative solutions for monitoring, tracking and maintenance. This section addresses specifically the case of equipment, systems and components that are geographically distributed and require to conduct even physical maintenance and service. A good example is related to the reload process for gas tanks, or the check of medical equipment deployed in patient houses or hospitals. In these cases, it is

not possible just to operate remotely the software: it is necessary to develop a local and responsive capability to provide the service on site. In addition, in these cases, the monitoring and tracking of the equipment is also very important to increase availability, reduce losses and also to have an updated situational awareness. Indeed, another not negligible aspect is related to robberies and misuse of the equipment that could lead to reduced expected life and increase in life cycle costs. Due to these aspects, the author is evaluating the development of combined approach based on Augmented Reality (AR) and Virtual Reality (VR) to support training and remote supervision to operations and maintenance of distributed systems.

4.1 The proposed Solution

The author studied in the past the potential to use AR/VR to support maintenance of complex systems; for instance, studies were conducted on using these technologies on autonomous systems on AUV and USV to support the service (Bruzzone 2013).

Figure 31 Head Mounted Display in Virtual Prototyping

During the lasts years, also other solutions have been experimented by Simulation Team Partners for supporting AR and VR in multiple applications from Virtual Prototyping of Cranes to Electrical Boards and Marine Solutions (Bruzzone et al 2010).

Figure 31, Figure 32, Figure 33 and Figure 34 show different combinations of AR/VR devices during experimentation carried out by Simulation Team Members (e.g. DIME, Liophant, MAST, MSC-LES, CAL-TEK). They include Head Mounted Display (HDM), VR Googles and Glasses, AR Tablets and integrated HDM/CAVE.

4.2 Service Distributed Systems

The researches carried out by Simulation Team identified a specific case study in service for distributed systems. In particular the analysis addressed tanks, containers and equipment used to provide O_2 to industrial operators, Health Care Infrastructures and individual patients at home. In this case, the components/systems move from simple O_2 tanks to cryogenic containers and to respiratory devices. In addition, the application field include industries, public institutions and consumers.

4.2.1 Gas Container Service

Indeed, the Gas Container business sector involves big enterprises and include management and logistics of several hundred thousand containers of different type and size. This issue is even more crucial in Healthcare Sector. Given the average cost of a single unit, the container stock represents a significant capital investment for the companies; furthermore the containers, in particular gas cylinders, are easily lost or stolen and require to be controlled over wide regional distribution.

Currently, it results pretty interesting from major companies active in providing this service to investigate new solutions and architectures to track cylinder locations in the gas container business. This aims to reducing cylinder losses, improving containers managements and stock controls. In addition, the producers of medical ventilators result interested in developing new capabilities to remotely assist patients increasing direct supervision and reducing the manning required to maintain the apparatus.

Figure 32 VR based on Oculus and Game devices

Respect conventional solutions, the use of innovative technologies based on web applications, cloud approach and enabling technologies in terms of markers and trackers allow to create new ad hoc architectures supporting scalability and flexibility, as well as reusability in a wide spectrum of applications. In this sense the use of AR and VR creates synthetic environments to represent the current situation for management as well as training and educational activities. The author is currently investigating combined solutions to propose a specific configuration and a road map for developing a prototype and a pilot experimentation on a set of gas containers.

The research aims to finalize a feasibility study on configurations and architectures able to track and monitor medical gas containers and ventilators. This research is focused on creating a tailored solution to guarantee overall performance and benefits, taking into account constraints and reliability of the adopted elements. Indeed, the design of the configuration will be based on the following functions: capability estimation, costs and development times for virtual prototyping, tailoring and engineering, integration and implementation, verification, validation and testing.

The proposed solution is currently based on the integration, within a cloud, of different technologies such as AR, VR, Markers, RFIDs, Trackers, Webcams, Cloud Connectivity, Smart Phones and Web Applications to provide distributed services, tracking and training for medical ventilators, gas containers such as cylinders and cryogenic containers. The solution is expected to be available to support logistics and reduce risk of losses as well as to assist the patients remotely, limiting the need of qualified operators and supporting planned and preventive maintenance. In addition, this solution will be flexible for being extended to other sectors where the containers are used (e.g. industrial application for O_2)

One major achievement is using the Augmented and Virtual Reality for remote support of the service, training and supervision of the equipment within the proposed architecture. This further increases the benefits of the architecture and prepare a large number of operators through distributed training.

Figure 33 Solution based on tabled and AR

Figure 34 AR solution based on web application

4.3 **VV&T**

It is fundamental to conduct integrated Verification, Validation and Testing (VV&T) of the proposed solution, in order to guarantee its effective application.

From this point of view, it is proposed to use the AR and VR environments to conduct tests with Subject Matter Experts (SME) and to evaluate reliability, effectiveness and efficiency.

Also, it is proposed to adopt different techniques during the development of the proposed solution (e.g. walk through, face validation, virtual examples). The dynamic testing on the virtual simulator and the use of Augmented Reality, on real system and mock-ups, guarantees to perform early-phase tests, supporting the adoption of Virtual Prototyping approach. The author is currently working on developing a framework to be reused over different systems and component for conducting multiple experimentations. Dynamic validation on the experimental case is based on the application of Design of Experiments to identify critical factors and reliability of the proposed solution (Montgomery 2008). Moreover, the author is considering the use of smart phones and tablets as main support for AR/VR on the field and specific testing activities are on-going for identifying the hardware/software platforms to be used by the operators. The dynamic performance measurements on the proposed architecture is conducted, until now, mostly in laboratory, waiting to move to an external pilot test in synergy with a major industrial operator. Indeed, a specific complex element to be evaluated is the capability of this approach to be resilient respect non-cooperative behaviours, carried out by external people and final users, that possibly damage or alter the distributed systems to be maintained and its components.

4.4 Outcomes

The research shows the preliminary results on the use of Virtual and Augmented Reality for the remote service of components and systems. The proposed architecture guarantees the possibility to support local operators as well as remote supervision. In addition, the approach

provides a very effective framework for training and education for staff to be involved in service both remotely and in main control rooms. This approach is expected to reduce the cost of the distributed components/systems and to increase their reliability, leading to further reinforce the outsource services and the competitiveness of operators. The specific case related to the O_2 Containers and equipment is a good example where the use of this technologies demonstrated to be very promising.

The author is working to develop a first pilot test to demonstrate and promote this research track on the field in cooperation with a leading industry of the sector.

5 Artificial Intelligence applications in maritime Scenarios

Within the framework of MALICIA project, a stochastic discrete event simulator developed for the Italian Navy, the author has been involved in the development of an Artificial Neural Network which deals with using and customizing a stochastic discrete event simulation as a tool for supporting decision-making process in Maritime Interdiction operations by the MMI (Marina Militare Italiana, Italian Navy).

This study confirmed the potential of ANN on Maritime Interdiction with Special Attention to Illegal Immigration, therefore the current change in operations on South Mediterranean by the MMI suggested to focus the study on behaviour identification that could be generalized to support decision making in multiple scenarios.

5.1 Conceptual Model

Nowadays, Naval Maritime Interdiction framework includes missions of complex, specific and articulated nature.

The grand objective of the research is to investigate and develop the components of future Decision Support System (DSS) for maritime interdiction and detection of migrants' flows, especially when accessing south Europe through sea routes, and piracy.

The Neural Network module is a constitutive module of the Data Analytics component, one of the three major elements composing the complete architecture proposed in Figure 35 addressing DSS adopting simulation.

The research is expected to provide support to Smart Planner and Data Analytics through automated intelligent controls, and also through interactive use by the Decision Makers to further investigate alternative COA.

The research carried out is investigating this innovative approach and promote the use of stochastic discrete event simulation as a strategic tool for supporting decision-making process in Maritime Interdiction operations. The case study is set in the anti-illegal immigration operations framework.

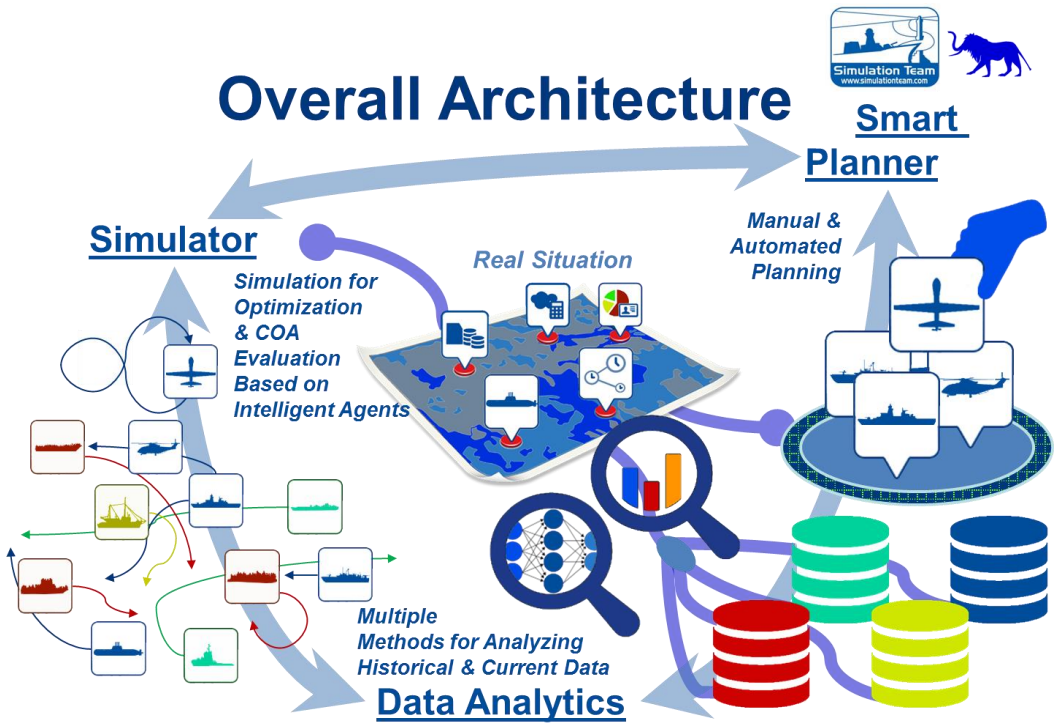


Figure 35 Overall architecture of the Federation of Simulator

5.2 Purpose of the ANN Experimentation

In order to train the ANN it was necessary to create a scenario and to define a goal; based on the discussion with Marina Militare Italiana (MMI) the author finalized the ANN for detecting and identify critical aspects related to surface vessels; in particular it was decided to use data related to the combination of track evolution, manoeuvring and boundary conditions (e.g. visibility, wind, current, etc.) to identify vessels conditions; in particular the aim of the research was to develop two neural network aiming, the first at identifying the presence of immigrants in the surroundings of the ship, the second to identify the presence of possible malfunctions or breakdown on ships. In facts it has been noticed that vessels detecting an immigrant boat often smoothly change course to avoid to be involved in the Search and Rescue operations (SAR), nonetheless vessels are anyhow subject to frequent change in course for navigation purposes, reacting to the sea state, as well as to avoid collision with other boats and ships, therefore the situation of the traffic and the nature of these changes have some marginal difference (e.g. early change of course, no ships with AIS on board in the surroundings, etc.); those marginal conditions are very hard to be defined, therefore it was decided to investigate if an ANN could be trained to learn the correlation and properly identify the behaviours described above (illegal immigration/malfunctions). Indeed, the results for the immigrant detection network were pretty promising (around 80% of proper detection of such cases among several thousands) even if it could be necessary to extend this research to carry out other investigations and to fully integrate the ANN in the

smart decision support system. In similar way the analysis allowed to investigate if a cargo is affected by a malfunction forcing him to return back, or simply to slow down or to change final destination; obviously this situation is easier to detect and the ANN performs significantl better (around 94% of success)

5.3 Dataset and APSU

Data about the behaviour of ships including all the information required for proper learning and understanding the situation are the basis for training an ANN. Due to these reasons it was requested to have access to data. The results showed in the following are obtained with public domain data, though, available to all from the web. Despite the unclassified data collected are not enough to define a good statistical data set the results obtained provided clear positive results using different kinds of ANN as proposed in Figure 36.

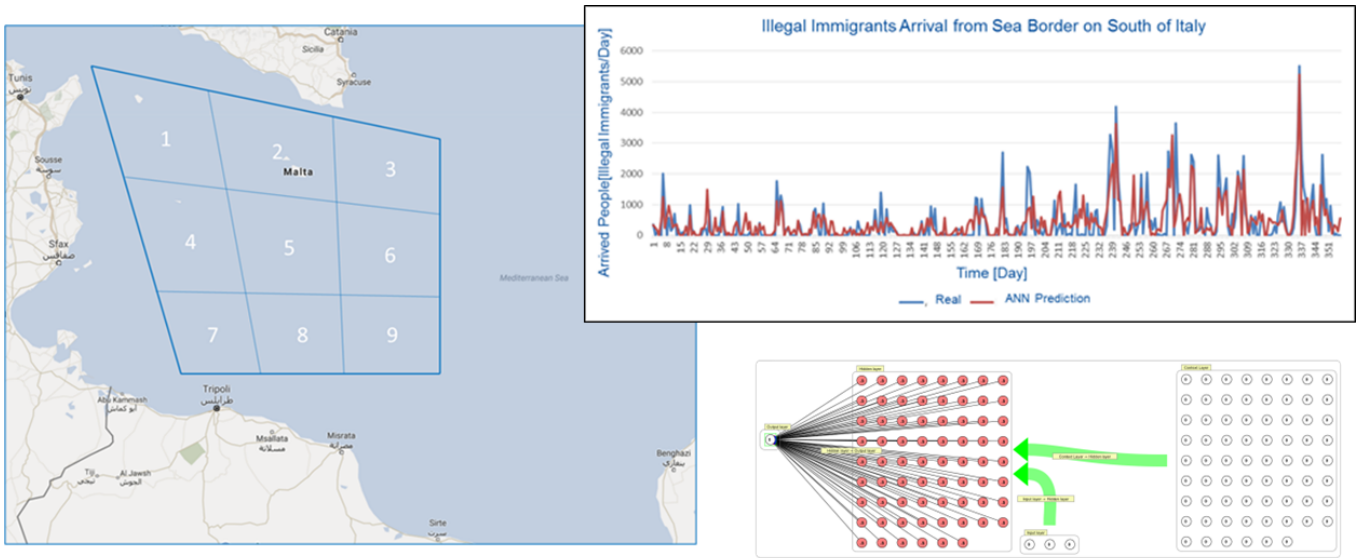


Figure 36 Neural Network used to investigate flows of Migrants over different areas

The author developed a simulator to generate the data reproducing a scenario in South Mediterranean where there is presence of Cargo Vessels, Small medium Size Boats as well as Immigrants surface units such as RHIB (Rigid Hull Inflatable Boats).

The Simulator used to feed the neural network is part of the research and has been specifically developed by Simulation Team. This module is called APSU (Automatic Proactive Simulator for Unified track generation) and allows to set different characteristics to generate the scenario from few ships to thousands; the simulation generates AIS data coupled with information about the boundary conditions and behaviours as well as traffic parameters that could be used to understand suspect conditions; the simulator spreads wind, visibility, current, sea and other variables all over the map and time horizon using publicly available data, with information available from the web; errors could be introduced as well as reaction to specific situations. The GUI of APSU is proposed in following figure, while details on data generated and related experimentation by Artificial Neural Networks is following in next chapters.

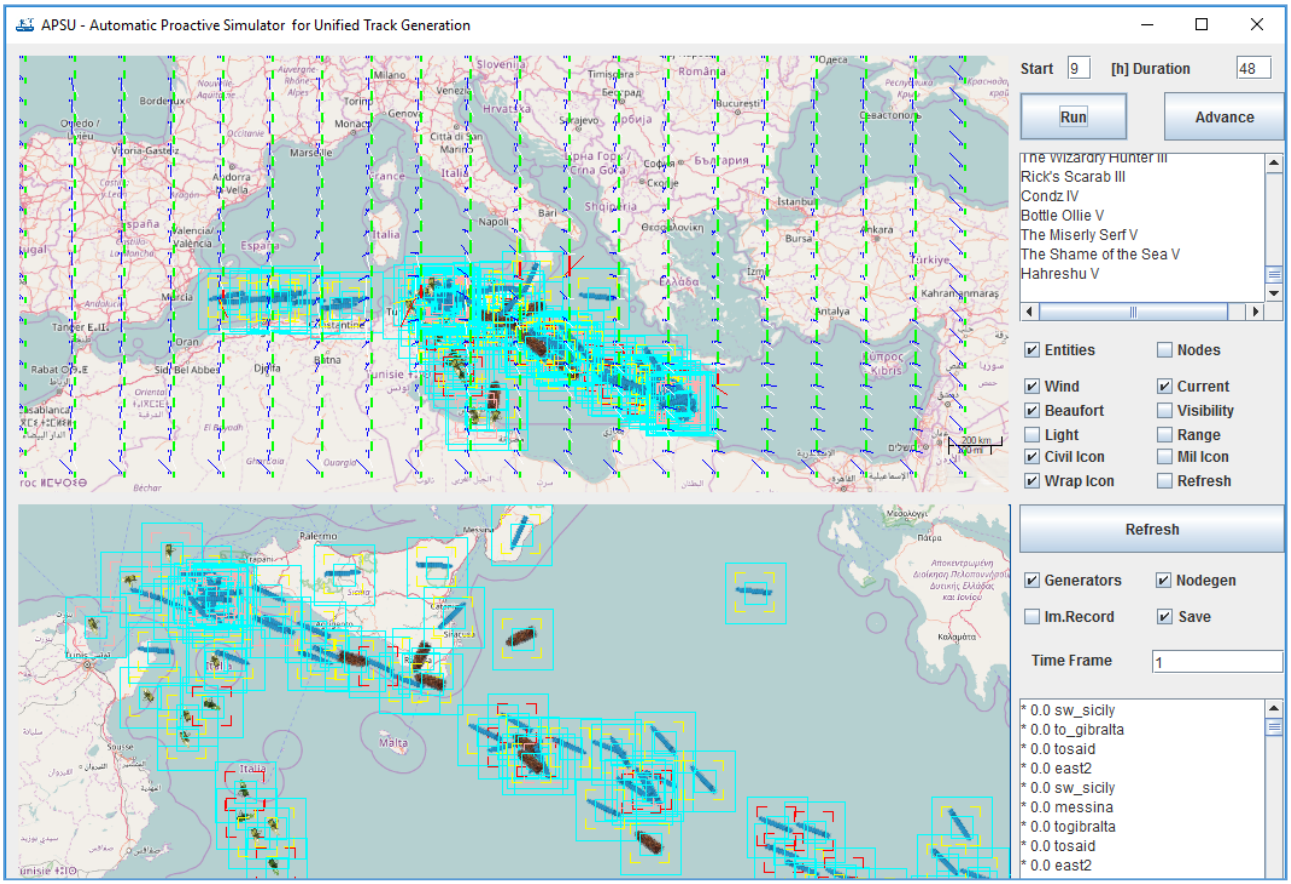


Figure 37 APSU GUI, Simulated Situation for Data Set Preparation. The indicators on the upper maps identifies sea state, wind force and direction, current, visibility, as well as the vessels in the scenario

5.4 Neural Network Description

As stated above the purpose of this research is dual, in particular is to identify from sea-state the ship size and attitude (represented by the course and speed, and thus their variation over the time) the presence of possible illegal immigrants' boat or if the vessel is suffering from malfunction and mechanical failure. To this end two distinct ANN have been developed.

The networks are feedforward, backpropagation neural networks, with two intermediate layers (named Hidden layer). The Artificial Neural Networks architecture has been refined

through a test campaign devoted to investigate the number of neurons, the training algorithm and the type of neuron transfer function. The neural networks have been developed using Matlab NNTool.

The inputs to the neural network are 42, specifically:

- Sea State based on Beaufort Scale
- Vessel Size, distinguishing between fisheries boat and cargo ship
- Record of the last twenty course sampled over the time
- Record of the last twenty advance speed sampled over the time

Beaufort	ship/boat	speed0	course0	speed1	course1	speed2	course2
3	1	16	338	16	292	16	2
2	1	18	110	18	110	18	1

Figure 38 Input Example, until the 3rd speed and course

The output, depending on the ANN considered, are:

- Indication of the presence of migrants inducing the ship to manoeuvre (1= ship is manoeuvring to avoid migrants, 0= the course of the ship is not influenced by the presence of immigrants)
- Indication of the vessel state (from 0 to 5 as expressed in the list in the next Section).

5.5 Tests and Experimentation

A Deep Neural Network architecture with two hidden layers has been adopted. The number of neuron for each hidden layer has been selected optimizing the results obtained with the Network. In particular the combination of neuron is:

- 20 Neurons in Hidden Layer 1 and 10 Neurons in Hidden Layer 2
- 30 Neurons in Hidden Layer 1 and 20 Neurons in Hidden Layer 2
- 40 Neurons in Hidden Layer 1 and 30 Neurons in Hidden Layer 2
- 50 Neurons in Hidden Layer 1 and 40 Neurons in Hidden Layer 2

The networks have been trained with Bayesian Regularization and Scaled Conjugate Gradient algorithms, suitable for difficult dataset as in this case, given the complexity of the framework and the number of input variables.

The transfer function tested are Log-Sigmoid and Tan-Sigmoid, well suited for pattern recognition.

In Figure 39 it is shown the architecture of one of the ANN developed, the numbers on the bottom of the Input, Hidden and Output layers indicate the number of neuron, while the curve symbol in the blue frame indicates the transfer function type (in this case Log-Sigmoid in the hidden layers and linear for the Output layer)

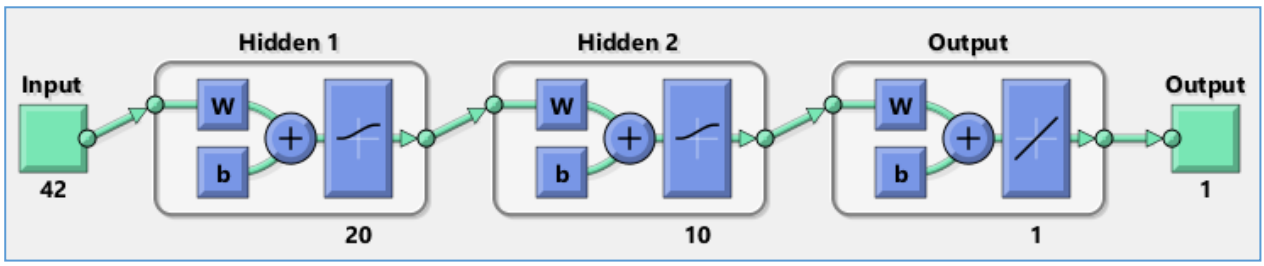


Figure 39 Neural Network Architecture

There is a distinction between the quantities computed to evaluate the immigrants and the malfunction ANN performances.

In the first case the output of the neural network have been first compared with a threshold level, then compared to the target, this gave an overall precision of 99.4% for the best suited ANN. Due to the reduced number of immigrants versus the number of ship daily passing the Strait of Sicily a second precision indicator is established, computing how precise the network is to detect the presence of immigrants, comparing the total number of immigrants detection with the count of the times the ANN agreed with the target value in case the target value meant the presence of immigrants. This gave a precision, for the best case of 80%.

In the latter case, for the Malfunction identification network, other two indicator have been computed. To explain the nature of the indicators is necessary to introduce the malfunction classification nature. In APSU simulator 6 types of ship state are codified:

- 0= vessel is fine
- 1=vessel is suffering a malfunction forcing the captain to reroute to the closest available harbour at cruise speed
- 2= vessel is suffering a minor malfunction allowing the captain to safely reach destination harbour without reducing speed
- 3=loss of propulsion power, vessel is drifting by
- 4= vessel is suffering a malfunction forcing the captain to reroute to the closest available harbour at a reduced speed, between 2.5 and 4 knt

- 5= vessel is suffering a malfunction forcing the captain to reroute to the closest available harbour at a reduced speed, between 4 and 10 knt

The indicators are meant in this case to compute the precision of the ANN identifying the malfunction code (0, 1, …, 5), and the precision of the ANN identifying if there is any kind of issues, the last one trough the occurrence of the only "0" ship state.

The analysis showed that the network would very precisely tell if the ship has any kind of malfunction, and less likely tell which kind of malfunction the ship has.

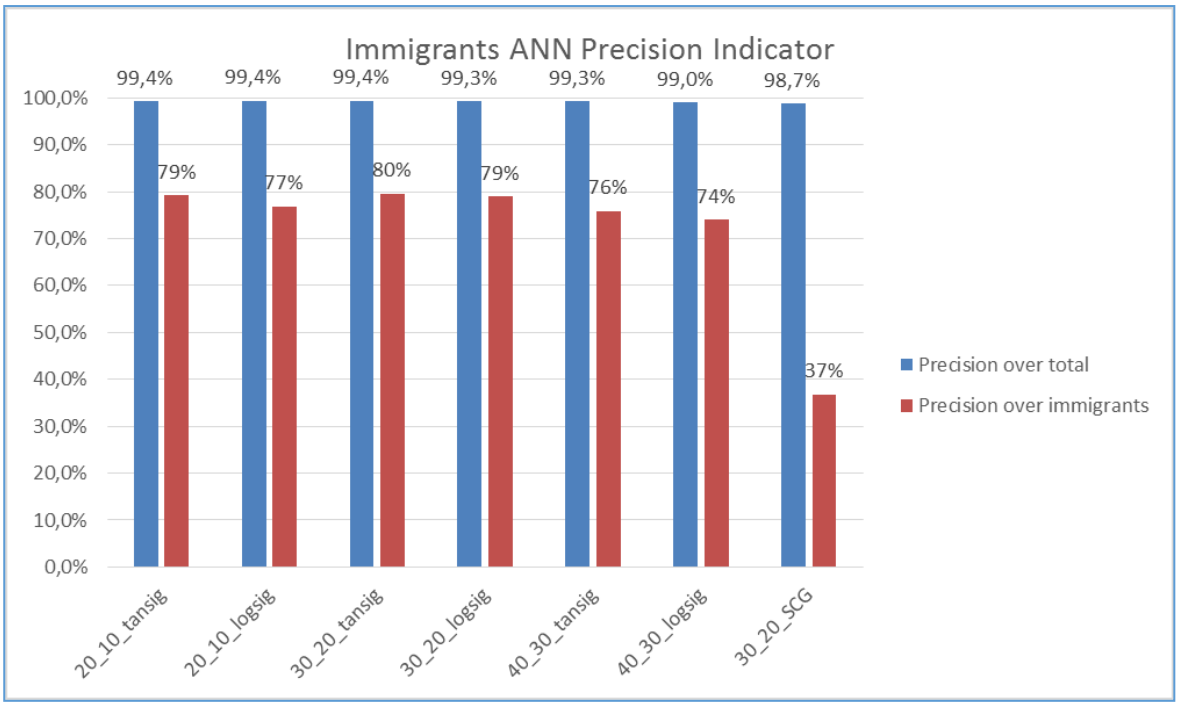


Figure 40 Immigrant ANN Performances

For the Immigrant Identification Network the results showed a subtle influence of the number of neurons, with the best solution being first and second hidden layer of respectively

30 and 20 neurons; whereas adopting Log-Sigmoid transfer function has a slightly negative influence on ANN performances.

On the other hand, adopting SCG training algorithm resulted in a dramatic drop in network performances.

The analysis clearly leads to the definition of the final architecture of the ANN, whose characteristics are:

- 30 Neurons in the first Hidden Layer and 20 in the second
- Bayesian Regularization training algorithm
- Tan-Sigmoid neurons transfer function

Similar conclusions can be thrown on the analysis of the Malfunction Identification Network, leading to the definition of the final ANN, being:

- 20 Neurons in the first Hidden Layer and 10 in the second
- Bayesian Regularization training algorithm
- Log-Sigmoid neurons transfer function

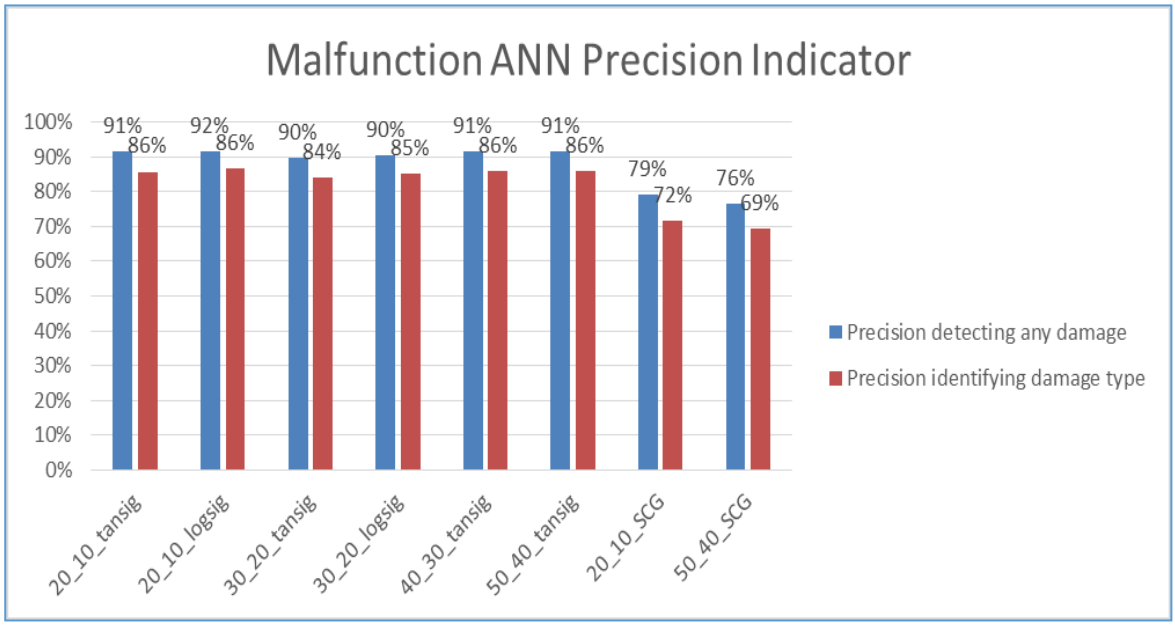


Figure 41 Malfunction ANN Performances

The performances indices for this network are:

- 86% precision in the identification of the type of malfunction
- 92% precision identifying possible malfunction

5.6 Networks Training Performances

The figure below shows the indicators at the completion of network training. In general, the network stops training when one of the parameters listed in the figure reaches its threshold value set at the beginning during the design phase of the network. In particular the green bar indicates that the network stopped training when Mu parameter reached its threshold value, where Mu is an indicator of the Neural Network training gain.

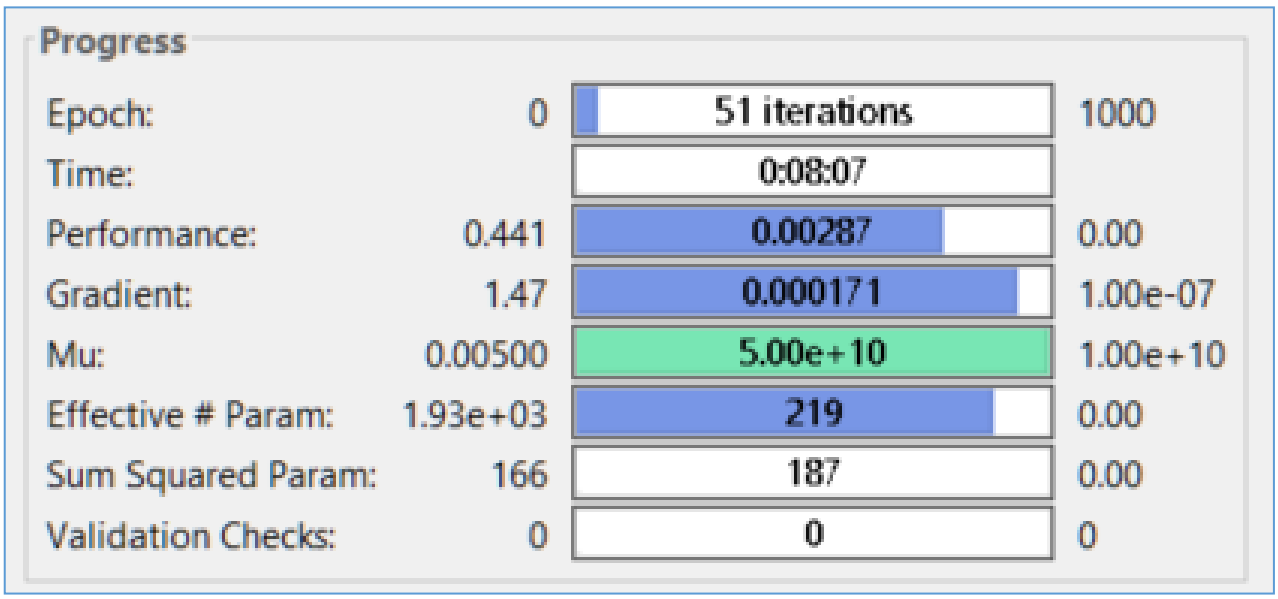


Figure 42 Immigrant Network Training Information at Training Completion

The Malfunction network stopped training due to the limit in the training iterations. Despite this is not the best way to stop network training it proved to be sufficient to define the network adopted as ultimate in this case study. In facts the results have been proven to be sufficient to meet the threshold set on the precision indices.

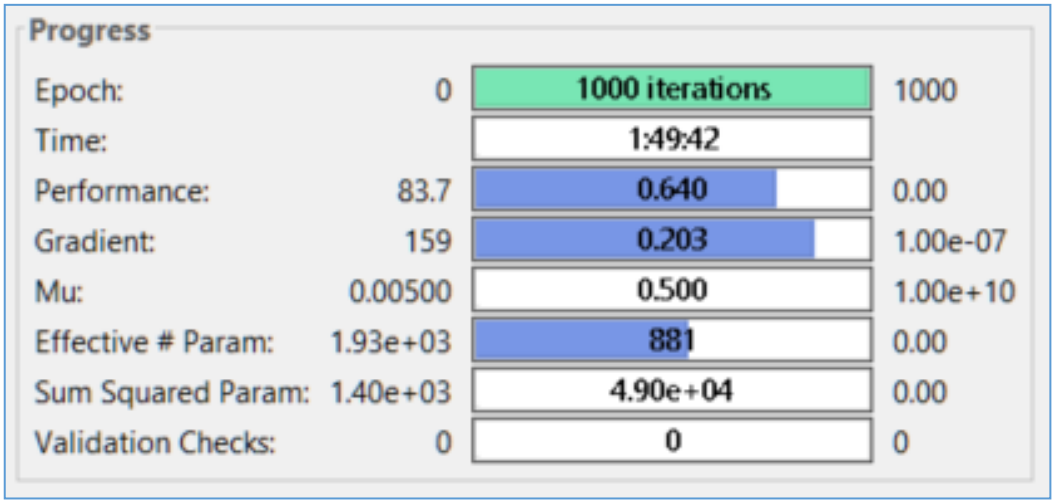


Figure 43 Immigrant Network Training Information at Training Completion

5.7 Outcomes

The approach proposed in this study confirms that the researches on ANN obtained interesting results; in addition, respect basic state of Art Simulation Team decided to prepare a demonstration on the specific field of Marine application as well as an experimentation with very good results also on challenging problems.

The use of data numerically generated by APSU Stochastic Discrete Event Simulator were very useful to conduct public domain preliminary tests described in this section. Future research will focus on real data as well as more complex scenarios and the integration of the ANN tool in the architecture of the Smart Decision Planners adopting HLA Interoperability Standard. It is very interesting to note that the capabilities were consistent with previous researches in terms of learning algorithms and ANN architecture and could be used for creating smart dynamically learning artificial intelligence solutions for this context.

6 Modelling Population Reaction to attacks on critical infrastructures

Critical infrastructures are not only located off-shore. The marine environment indeed embraces coastal areas, which are generally densely populated.

The author has been involved in a series of initiatives devoted to design a federation of simulators devoted to support Disaster and Crisis Management.

In facts disasters are one of key threats to the modern society and their devastating effects caused a lot of losses in terms of human lives and economy along last years; considering their complex nature of these phenomena combining many different elements, it is evident the opportunity to integrate models and simulators into a common interoperable framework. This research proposes an innovative approach to these issues as well as an overview of existing simulators, models and databases available for this purpose. The final goal is to create an open architecture to support crisis management by evaluating COAs, damages, risks, evacuation plans and population impacts & reactions.

During the years several studies have been carried out for addressing disasters, emergencies and crisis management trough simulation and modern M&S advances are providing new opportunities in this sector (Bruzzone et al.2015a; Gupta et al. 2016). The use of M&S (Modeling and Simulation) allows to address multiple needs including the capability to estimate the preparedness level and to boost training and education, as well as to reduce

vulnerabilities and address risk assessment (Zaharia et al. 2009, De Hoop & Ruben 2010). In facts it could be very useful to create simulation frameworks able to combine together the disaster dynamics that usually is related to physical models (e.g. a toxic agent diffusion, an earthquake impact on buildings or a flooding over a region) with the operational aspects (e.g. standard operation procedures evacuation planning, relief operations) and to reproduce the whole scenario (Bruzzone & Kerckhoffs 1996). In facts by this approach it could be possible to evaluate and validate existent operative procedures respect some crisis scenario as well as to define new ones; in such context the use of agents-based simulation could be crucial to properly reproduce the interactive behaviours of the actors involved in this mission environment (Mustapha et al. 2013; Bruzzone et al.2014a). The author proposes hereafter an approach and related experimental plan to address CDM (Crisis Disaster Management) through interoperable simulation.

6.1 Modelling addressing Disasters & Critical Infrastructures

Crisis become even more destructive when the the target are critical infrastructures that could generate domino effect which can further reinforce damages, casualties leading social collapse (Brassett et al.2015).

In this case, it is necessary to evaluate the impact of industrial facilities releasing hazardous material or generating huge explosions, as well as water resources unavailability, and communication network or power grid collapse (Griffiths 2012; Diers & Donohue 2013, Bruzzone et al. 2014a; Burgherr et al. 2015; Tremblay 2016). In facts, these infrastructures

are requiring many years to be finalized, requires big investments and are characterized by limited life cycles; so it fundamental adopt a scientific approach in order to harmonize the plan of new installations respect dynamic evolution of the needs and of the existing resources over a long time horizon covering several decades (Zio 2016). In facts, it is necessary to be able to evaluate quantitatively the potential impact of natural disasters on these critical infrastructures as well as the mutual interconnections leading to risk of "cascade failures" (O'Rourke 2007; Szymanski et al.2015). It is evident the benefit of adopting a technical approach able to address both analysis of the current overall resilience and planning the future one considering their lifetime. (Bruzzone et al.2008; Francis & Bekera 2014). Indeed the reduction of the risks of such events represent a main goals of International and National Organization & Agencies as well as very important subject for major industries working.

Considering the high degree of stochastic factors and variables as well as the high number of mutual interactions among many different elements, M&S results the most promising methodology; however it is necessary to adopt interoperable simulation solutions able to address these multiple aspects; in facts by using interoperable simulation standards it becomes possible to define guidelines for creating a common framework including available models, new simulators as well as support tools already in use for crisis management (Bruzzone et al.2015a). In facts in this context the necessity to use simulation is fundamental to properly reproduce not only the crisis and damages to infrastructures, but also population response and effectiveness of countermeasure actions based on their dynamics.

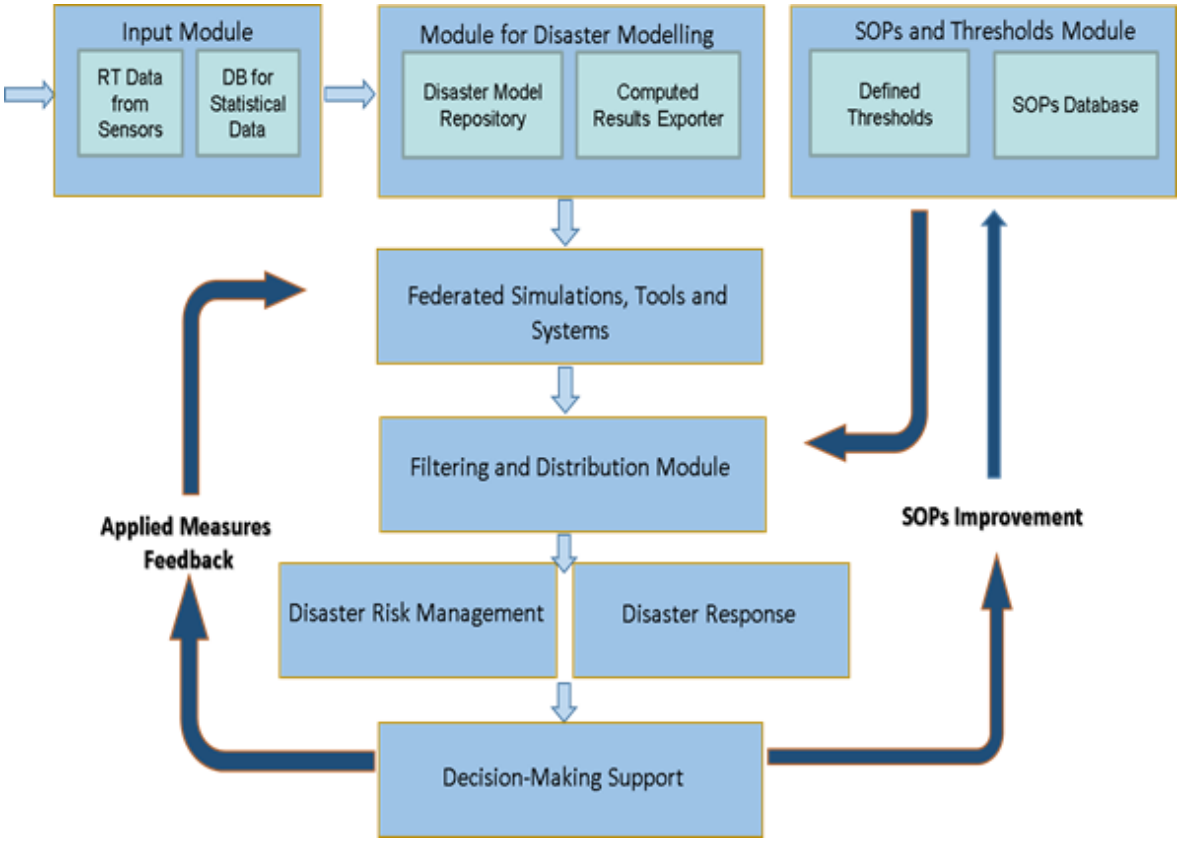


Figure 44 Architecture of the CDM System

So, due to these aspects, the author suggests to create a CDM System integrating interoperable combined solutions; in fact, it is proposed to mix different tools, models, simulators and Intelligent Agents (IA) for reproducing the crisis as well as population behaviour (Bruzzone et al.2011b, 2014b). The most promising and effective approach to create an interoperable federation of simulators should be based on use of modern reliable interoperability standards, such as High Level Architecture (HLA) IEEE 1516; indeed this allow to integrate the different components and to orchestrate all the available simulation models in an unique framework available for the different stakeholders (Kuhl et al. 1999).

By this approach it could be possible to federate together with the simulators also other modules, components and, even, real equipment; the resulting federation could act as an unique solution consistent and reliable that could be used for different purposes such as Training and Decision Support.

The necessity to create new solutions available for being used by the different authorities in relation to crisis management is a fundamental step forward for reinforcing the fidelity on data, models and analysis approach in this sector as well as to enhance the effectiveness of educational and training in this field (Bruzzone et al.2009; Massei et al.2010; Raybourn 2012).

Indeed, the innovative benefits provided by such federation include the capability to include and test each specific expertise required to deal with this different crises (e.g. hazardous material spills vs. flooding) and on the different operational areas (e.g. containment, evacuation, communication, strategic planning). In facts, simulation allows to evaluate the capabilities needed to properly face specific disasters as well as to identify the actions to create and enhance the operational interoperability within the different players (e.g. military, firefighters, civil protection, police, health care, NGO, etc). The author have combined different simulators and tools as federates into an HLA interoperable simulation by using available models such as IA-CGF, IDRAS, JCATS, ST_CIPROS, ST_CRISOM & SWORD (Prochnow et al. 2000; Browers et al. 2003; Bruzzone et al.1998, 2011b, 2015b; Ruiz et al.2013).

The main idea behind these activities is to define guidelines to support the easy and reliable integration of existing tools and models within this simulation as well as to demonstrate the potential of this approach by experimentation and support to exercises.

6.2 NATO Expectations from Disaster Simulation

NATO's primary contribution in case of disaster is the coordinating, liaising and facilitating functions working with other major actors, including Governmental and Non-Governmental Organizations. Therefore NATO is strongly interested in simulation activities related to disaster scenarios.

The M&S research provide significant data and tools to build modern M&S solutions applied to disaster scenarios, and the author is currently involved in researches, test campaigns and experiments in international context to proof simulators capabilities and their ability to be federated in HLA.

By combining civilian and military crisis management and disaster response instruments NATO is effectively contributing to a Comprehensive Approach.

The goal is to anticipate and enhance the Alliance and Nations' civilian and military capabilities for crisis management and disaster response. (Milkov 2017)

With the increased probabilities of civilian/military cooperation being required, enhanced understanding and trust will be needed between civilian and military entities, including non-governmental stakeholders, to ensure effective and efficient strategic coordination, planning and execution of disaster relief operations in support of protecting critical infrastructure. In

this regard, NATO is pushing to develop distributed and network capabilities for training and education to be integrated and contribute to the growth of existing National capabilities (Nikolov 2015).

6.2.1 **Joint Research Activities**

NATO-STO (Science and Technology-Organisation) has tasked NATO Modelling & Simulation Centre of Excellence NMSG-147 with the specific goal to develop the "M&S support for Crisis Disaster Management & Climate Change Implications".

The NMSG is chaired by CMDR CoE (Crisis Management and Disaster Relief Centre of Excellence) in Sofia, Bulgaria, and includes several Participating Nations and Organizations: Germany (Co-Chair), Austria, Bulgaria, Italy, SLO, USA, M&S CoE (Modelling and Simulation Centre of Excellence), JCBRN CoE (Joint CBRN CoE), ACT (Allied Command for Transformation), JFTC (Joint Force Training Centre), different Universities in Bulgaria, Germany and Italy, as well as industries.

The intended purpose of this group is to elaborate the theoretical, methodological and technical framework for the establishment of a holistic crisis decision-making support mechanism (Nikolov et al. 2016).

The project has three main directions for analysis CDM in NATO in order to improve the E&T (Education & Training) and support the Decision Making Process in the Alliance:

- Analysis of Disaster Risk Management (DRM) Processes, preceding the development of the Operations Plan, represents the first direction:
    - Fast and accurate Disaster Risk Analysis;

    - Comprehensive approach and correlation assessment among hazards;
    - Prevention and Preparedness Measures proposals.
- Assessment of the Disaster Response, during NATO operation, is 2nd directions:
    - Fast and accurate Disaster Assessment (DA)
    - Dynamically generated proposal for Response Plan.
    - Lessons Learned Process (LL)
- Development of modules for realistic modelling and presentation of different disaster types is the 3rd direction devoted to the purpose of education and training, experimentations, tests and validations.

The methodological approach of this group respect to this study is orientated to NATO-CD&E (Concept Development and Experimentation) procedures.

NATO-CD&E offers the right methods to incorporate M&S in scientifically valid tests / trials / experiments, thus give an agreed common ground for sustainable results.

At the end of the study, these achievements are expected to be used as a basis for:

- Development of 'Standing Operating Procedures'
- Development of technical (simulation) suites / federations
- Justification for investment of financial resources
- A baseline for further studies on simulation of crisis management tools and models

6.3 Experimentation Planning

In the proposed study it is intended to conduct test trials to actually federate existing disaster models in accordance with the above-mentioned architecture. These trials became CD&E-experiments with an independent analysis according to NATO-CD&E procedures.

The first experiment was conducted in March 2017 and it was designed as a 'Discovery Experiment'. The aim was to demonstrate the capabilities of existing disaster and C2-simulation tools as well as to federate as many as possible of these modules.

The results were impressive, however it was found that only few disaster models were available and able to be federated in HLA; in this occasion simulations tools, such as SWORD, ST-CRISOM, HPAC, KORA, MILSIM/EDMSIM, COBRA, ICMS and EMERSIM have been tested. The second experiment in October 2017 serve as a continuation of the first one, with the same aim and seemingly more federates. ST-CRISOM, among others, will play a significant role here as point out in the following for population modelling.

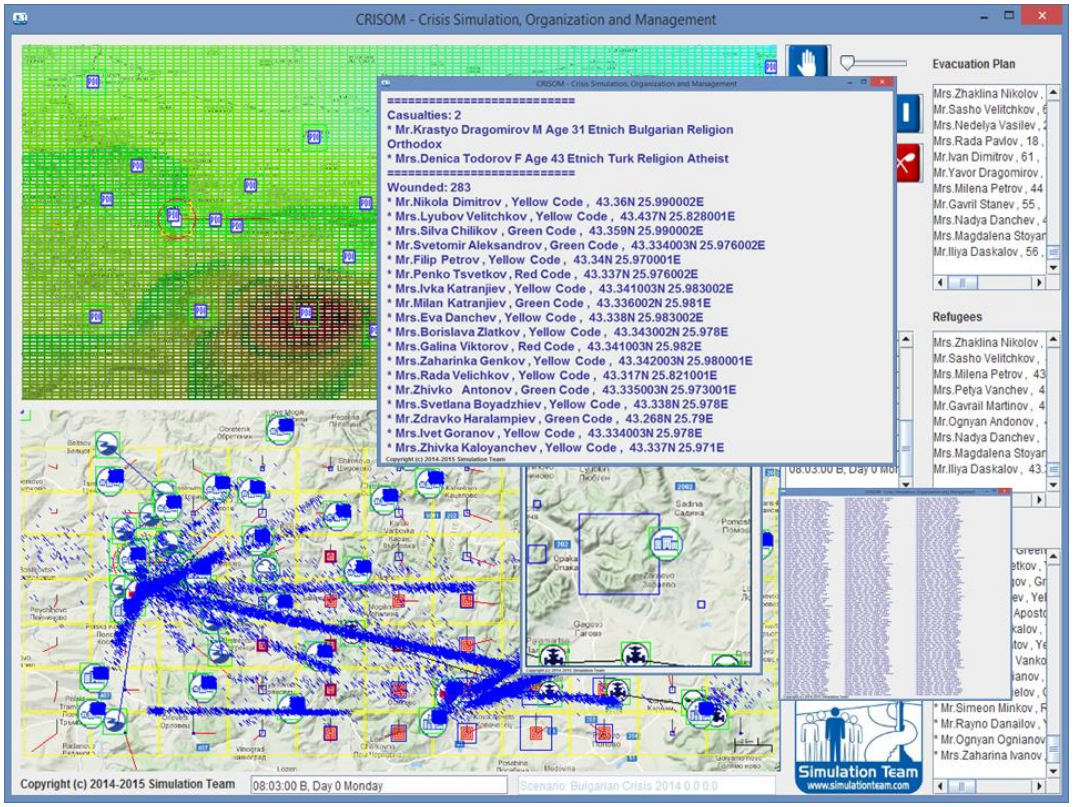


Figure 45 ST_CRISOM Interface

Other two experimental tests are planned during the 2018. Those tests, so called 'Refinement experiments', are devoted to evaluate the performances of the described architecture with its modules. In facts, a 'Demonstration/Life-Field' experiment is planned during Viking'18 exercise and a final validating experiment will happen in the first quarter of 2019 as Final Demonstration of the results from the NATO group.

6.4 Federation, Federates & Scenario

One of the goal of this research is to address the technological issues related to CDM and technological evaluations about interoperability among the simulators will be conducted.

Major issues are related to evaluate the different FOM (Federation object Models), RTI (Run Time Infrastructures) as well as the effective features of existing models and the federation/federate computational issues during the experimentation. Obviously, HLA allows to integrate into the federation also new models together with legacy systems and it could be possible to add additional entities if available.

It is important to outline that one major goal of this initiative is also to create a framework enabling interactions among M&S scientists and Operational Subject Matter Experts. This collaborative simulation environment is very important because crisis management usually combines military and civil resources that have different background, procedures, technologies and priorities that could heavily benefit from working together on a common validated framework and they are both required to complete effectively the VV&A of the simulation (Balci 1997; Amico et al.2000). In facts, the check about conceptual interoperability among the different conceptual models will result in a major benefit as soon as technological interoperability will be guaranteed; a major step in this direction will be passing the integration test during the planned experimentations.

For this scope, the author has been working with a pool of experts from different background (military, scientists, developer) to finalize the details of the proposed federation and to understanding how to use it to properly and effectively to demonstrate it for crisis management, identifying data to be shared and what interactions are required among the different federates.

The author defined a specific scenario in order to proceed with the concept validation, experimentation and testing on the models; in particular the mission environment set in a European Country and it should be possible to address different kinds of crisis such as: Flooding, CBRN (Chemical, Biological, Radiological and Nuclear) Threats and Fires. These subjects are quite articulated and combine different elements such as GIS data sets (Geographic information system), Flooding and Hydraulics Models, CBRN simulators, Fire simulators and Population Simulation. In general, the Federation should demonstrate its capability to estimate the effects of alternative decisions on the whole system including the population behaviour: for instance, the effectiveness in placing sandbags during a flooding or the responsiveness of the resources in applying evacuation plan during the simulation.

6.5 Modelling impacts on Population

In the proposed experimentation the modelling of impacts on Population and its dynamic reactions to events and crisis is a major issue and hereafter is proposed a specific simulator devoted to address these issues: ST_CRISOM (Simulation Team Crisis Simulation, Organization and Management).

In facts ST_CIRSOM includes meta-models of disasters (e.g. flooding or CBRN event) and use Intelligent agents to simulate the human behaviours and reaction of the population (Bruzzone et al.1998, 2015a, 2017a).

ST_CRISOM adopt a Multilevel and Scalable approach (tactical/operational/strategic) and is able to simulate individuals within a large region with a different level of aggregation,

down to the single entity or simulating crowd behaviour from a region up to an entire country.

Evaluation of boundary conditions affecting the disaster evolution are crucial and often need to be estimated and/or extended based on partial data; due to this reason ST_CRISOM considers the 3D landscape (orography) of the terrain to properly diffuse several boundary conditions (e.g. wind, rain, temperature) in space and time and to reproduce complex phenomena such as flooding, CBRN or hazardous material spills that have impacts on population behaviour.

ST_CRISOM is equipped by an acquisition tool, developed by Simulation Team, able to import data from GIS databases to feed the simulation.

The population and GIS information are elaborate with the simulation by meta-models devoted to estimate the diffusion of the crisis. For instance, to distribute the rain over an area and related flooding, the simulator considers the impact of showers as well as rivers behaviour; the weather forecasts are elaborated over the region, respect time advance and boundary condition (e.g. wind speed and direction, pressure).

Figure 46 ST_CIPROS MS2G

This process allows to generate the dynamics of rain taking into consideration the stochastic elements; the rainfalls are simulated and it becomes possible to quantify their impact on the different kinds of terrain based on its specific characteristics. In facts ST_CRISOM processes multiple layers reproducing both the terrain and the specific elements present on it as well as their functions such as:

- Rivers, Mountains, Lakes, Sea, etc.

- Buildings, Quarters, Villages, Towns, etc.
- Hospitals, Power Plants, Point of Interest etc.
- Pipelines, Power Lines, Cables etc.
- People, Social Networks, Interest Groups, etc.

Furthermore, ST_CRISOM simulates the human behaviour by reproducing the single individuals as well as their social network by using IA (Bruzzone et al. 1999, 2011b); the HBM (Human Behaviour Models) are attributed to people objects driven by the agents that consider different specific social parameters such as families, ethnic groups, level of instruction, social status, religion, political party, health status, age, gender, presence of impediments, etc. Population could be generated based on local statistics through Monte Carlo Simulation or acquired from databases.

The population is simulated by means of IA-CGF (Intelligent Agent Computer Generated Forces) developed by Simulation Team and their social psychological factors such as fear, stress, aggressiveness; these characteristics evolve dynamically during the simulation according to the events perceived by people objects as well as to the actions that they have carried out (e.g. escaping); the simulation engine is based on stochastic discrete events and allows to generate the scenario dynamics and to interoperate with other simulators as well as interacting with users. Each time a disaster occurs, the simulator reproduces its evolution and computes the list of the entities that are involved in the crisis; concurrently the agents related to people objects as well as to the entities (e.g. ambulances, first responder units) drive the simulation evolution; in this way it is possible to evaluate Key Performance Indexes

(KPIs) such as the casualties, areas affected by the crisis, logistics requirements, responsiveness parameters, etc. In addition, ST_CRISOM provides reports about people to be evacuated or to receive health care support including relative details (i.e. name sex, age, health status etc); such information could be aggregated in different ways to support training (e.g. evacuation list organized based on town quarters or streets).

ST_CRISOM is able to also manage units and entities devoted to countermeasure directly controlled by itself or to interoperate with other ones provided by other federates; these are visualized and have an impact on the different agent behaviours; obviously this represent an interesting opportunity in the federation to be developed allowing to let other constructive simulators at different granularity level to move units on the terrain creating interactions with population and crisis evolution.

Currently ST_CRISOM operates as HLA time constrained and time regulating federate with the capability to run real time as well as faster-than real time; in facts this simulator has been experimented in conjunction with other simulators developed by Simulation Team (i.e. IDRASS, DIEM-SSP, IA-CGF NCF, NCF EQ, TRAMAS Katrina Like, DIES IRAE, SIMCJOH VIS & VIC).

Another module is represented by ST_CIPROS (Simulation Team Civil PROtection Simulator) proposed in Figure 46. ST_CIPROS is as another element based on MS2G (Modelling, interoperable Simulation and Serious Games) paradigm and it provides an immersive interactive framework for the decision makers and their virtual staff to take decisions and to evaluate the consequence of alternative COAs (Bruzzone et al.2017a). In

the following paragraph the result of the experimental analysis conducted during the development of ST_CRISOM and ST_CIPROS are presented.

6.6 **VV&A**

A basic experimental campaign for ST_CRISOM Project has been conducted to address Verification, Validation and Accreditation (VV&A) of the simulators. Due to the non-linearity and the stochastic nature of the phenomena investigated, a careful experimental design is necessary for quantifying experimental error (Montgomery 2008). In particular the methodology used in this case is the analysis of the Mean Square pure Error (MSpE) to evaluate the temporal evolution of the experimental error due to the stochastic components. The MSpE analysis have been conducted on the output of the simulation, in particular for some KPIs such as the number of Casualties, Number of Injured People, and Quantity of Refugees and Evacuated people. The simulation is focused on flooding for a duration of three days for each run to cover the whole crisis; ten replications, with the same boundary condition have been used for considering the variance due to the stochastic components.

The results of the experimental campaign summarize the ANOVA based on evolution of the MSPE over simulated time for the three proposed output (shown in Figure 47, Figure 48 and Figure 49).

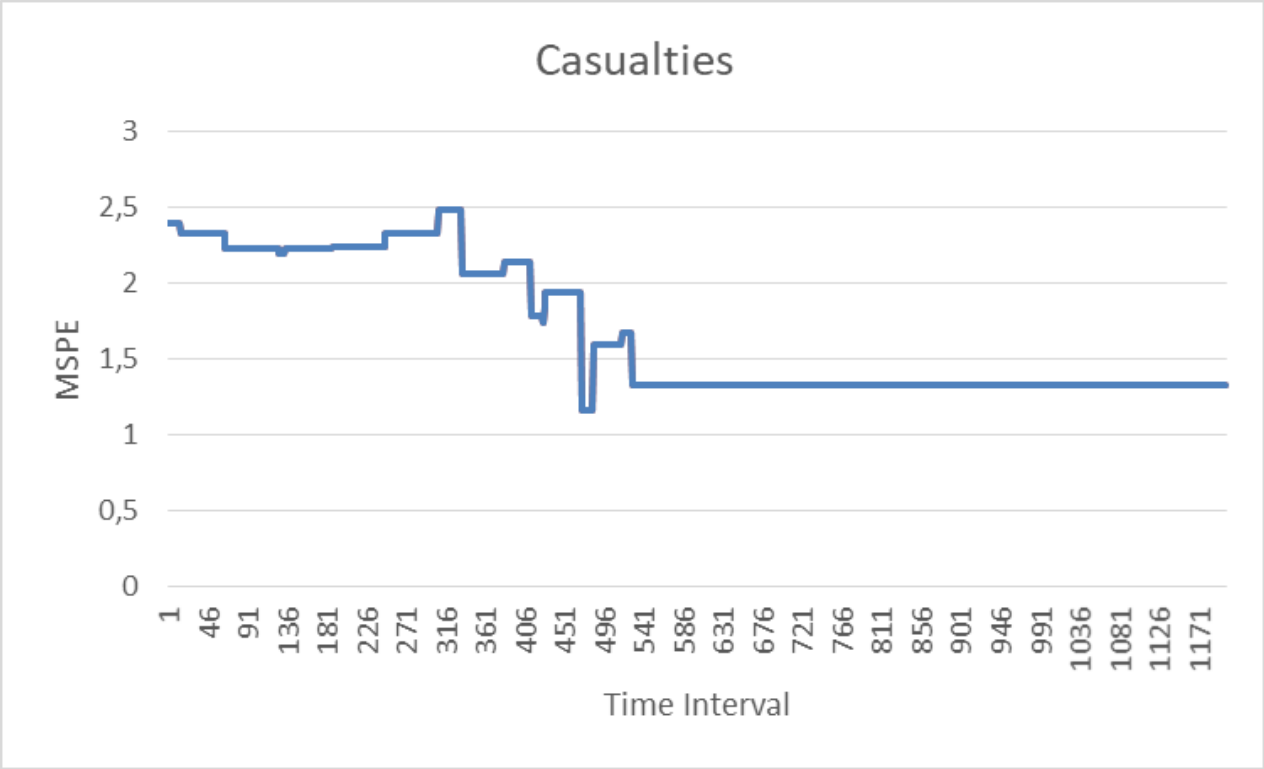


Figure 47 MSPE for the Casualties over time

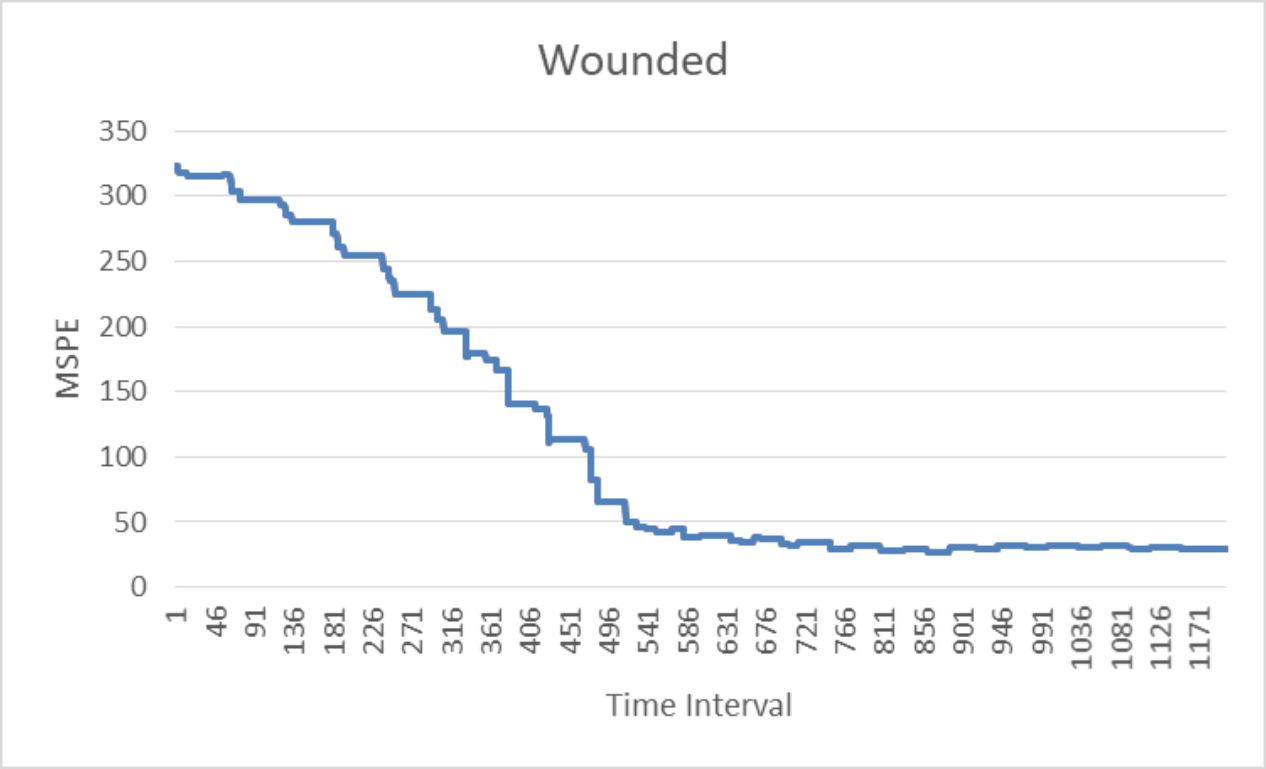


Figure 48 MSPE for the Wounded People over time

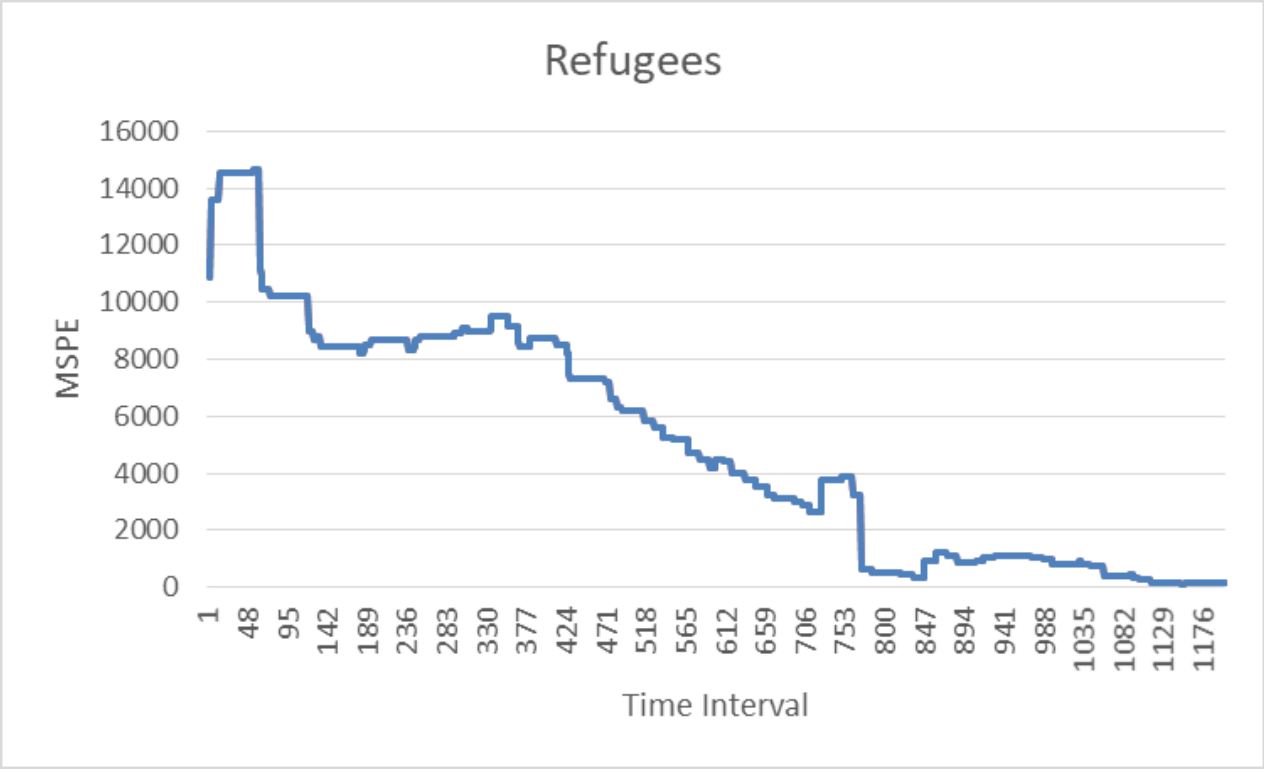


Figure 49 MSPE for the Refugees over time

In particular, from the analysis it is possible to assess the consistency and fidelity of the simulators. In facts, it is possible to measure the common trend of output variances that stabilize providing an estimation for confidence band of the output functions.

6.7 GIS and Data for Decision Support

The complexity of the above-mentioned framework requires to acquire a large quantity of data to cover both the different layers of the terrain as well as the social aspects. This issue turns even more critical in case of regions with high density of people as well as in large metropolitan areas that represent a crucial scenario for future analysis respect crisis management. Indeed, in near future, the availability of modern Decision Support Systems

(DSS) for crowded urban areas respect crisis management is expected to be a requirement for both civilian and military decision-makers. Therefore, these DSS are expected to not be limited just to crisis management, but to be required to support also other operational planning (e.g. logistics). In facts, since several years, NATO has activated a research on this direction devoted to create data sets to be used to investigate the challenges carried.

In the proposed scenario the simulation of such urban area results very interesting and require data; indeed, a metropolis Geographic Information System (GIS) such as the 2035 virtual "Archaria" megacity, created by M&S COE and Fabaris for the NATO Urbanisation Experiment 2015 and Urbanization Wargame 2016 is expected to include potential critical elements in support of training and planning processes in the context of civil protection. In facts this kind of GIS provides a real awareness on the terrain, including information about city traffic layer, hospital and beds, emergency rooms, police stations, military barracks, webcams, etc. These data are integrated within the GIS into a Common Operational Picture (COP) available to the emergency agencies and Citizens are enabled to actively contribute to the information cycle by feeding the DSS with their reports, post, chat, tweets, etc. (Lo Presti et al. 2016).

Due to these reasons "Archaria" is a good example of data source to feed the simulation and reinforce the validity of the scenario; in facts the military personnel are used to train and analyse scenarios by virtual and constructive simulation that could require high granularity information. In facts the traditionally military simulation systems and models reproduce mostly military units, platforms, orders, movements, logistics of military forces; just in some

case and by some specific customisations, it is possible to simulate civilian forces, organised in hierarchic structures (the so called “order of battle” ORBAT), therefore normally these simulators do not model with same accuracy the impacted populations. It is evident that this research need to fill up this gap by combining different simulators and data sources. The GIS could act effectively to cover the disaster region with special attention to the urbanized area in terms of information about the terrain, data on emergency, civil protection & military forces as well as details on the political, military, economic, social and industrial infrastructures. In facts it is possible to perform interesting analysis on the distribution of the population on the territory in different daytimes, thus providing data to simulate the effects of each disaster on the examined rea.

6.8 **Outcomes**

Close cooperation in the crisis management and disaster response domain requires forming appropriate military and civilian capabilities. These capabilities include information and intelligence sharing, developing and operating early warning systems (in support of creating a common situational awareness), as well as conducting crisis & disaster planning and response & preparedness for Climate and Disasters impacts on critical infrastructures (Nikolov et al. 2016).

An M&S Architecture effective in this field should have its initial operational capability established soon in order to be operational in time to support the planned NATO Crisis Management Exercises as well any regional Network projects or exercises and trainings and

it is evident the strong motivation of this research. Integrating these aspects, the NATO Force Structure would be better prepared for the next climate and disaster challenges and these systems will effectively support the national building resilience. Indeed, the proposed federation should create new capabilities and reinforce existing ones by improving operational interoperability based on a simulation able to combine together military and civilian models; in facts the use of these software solutions within an HLA federation is expected to support the capability development as well as Education and Training for joint civilian-military operations by engaging decision-makers, leaders and personnel.

7 Simulation of Power Plant Environmental Impacts within the Extended Maritime Framework

Another important aspect of the infrastructures within the Extended Maritime Framework is their impact on the environment.

This section reports on the proposed use of Modeling and Simulation to analyse the different Environmental Impacts of Industrial Facilities with special attention to Power Plant located within the Extended Maritime Framework. The approach proposed is based on combining different simulation approaches to be able to reproduce the phenomena affecting this context in a comprehensive way. The simulation experimental results are dynamically presented and updated within a Synthetic Environment, based on a Serious Game, in order to be able to augment the virtual representation with additional information. It is proposed a case study related to a Power Plant including different Gas Turbines located along the coast and the scenario include the evaluation of the emissions on the Atmosphere, Sea Water and Ground, the inclusions on this domains as well as their impact on the flora, fauna and social layers.

The concept of sustainability is evolving along years but the related basic foundations set by the Brundtland Commission in 1987 are still valid: “the sustainability of ecosystems on which the global economy depends must be guaranteed. And the economic partners must be satisfied that the basis of exchange is equitable” (Brundtland Commission, 1987).

To address this point, it is fundamental to evaluate in comprehensive way the whole ecosystems including human installations (Liu et al., 2008). The complexity due to the

explosive nature of the context, the long-term effects of the decisions overpassing human horizons and the presence of multiple interactions and stochastic factors make it evident the necessity to move out of qualitative approaches and to adopt quantitative methods (Belcher et al., 2004). Obviously from this point of view M&S result a strategic science to study these problems (Swart et al., 2004). Indeed environmental impacts (EIs) of industrial processes, considering both pollution and acute major hazards, are very complex due to the fact that involve a myriad of factors and elements related to intrinsic chemical properties (Reverberi et al., 2016) and physical aspects (Fabiano et al., 2015) whose mutual interactions are still not very well known. Despite these facts, the possibility of model relationships between environmental impacts, industrial plant characteristics and operational modes could strongly improve the understanding of these phenomena; indeed, dependency and combined effects could be estimated by designing a hierarchical relationship model (Bruzzone et al., 2010). By utilizing a risk matrix and defining a target line of consequence-frequency combinations, it is possible to perform a cost-benefit assessment and answer the question how safe is safe enough, considering both acute risk and chronic environmental risk as well as environmental sustainability (Vairo et al., 2017).

The author developed these models in the past, focusing on Logistics as well as on Port Operations supporting the development of Green Solutions for these frameworks (Bruzzone et al., 2009).

Recently, the evolution of policies on Greenhouse Gases had big impacts on industrial plants configuration, considering that several energy saving systems and policies, that are

consolidated and already operational, have to be dismissed due to the change in tax policies (Zhang, 2016); this situation leads sometimes to strange solutions that are not really "energy saving", but result effective in reducing taxes and fees (Burtraw et al., 2014).

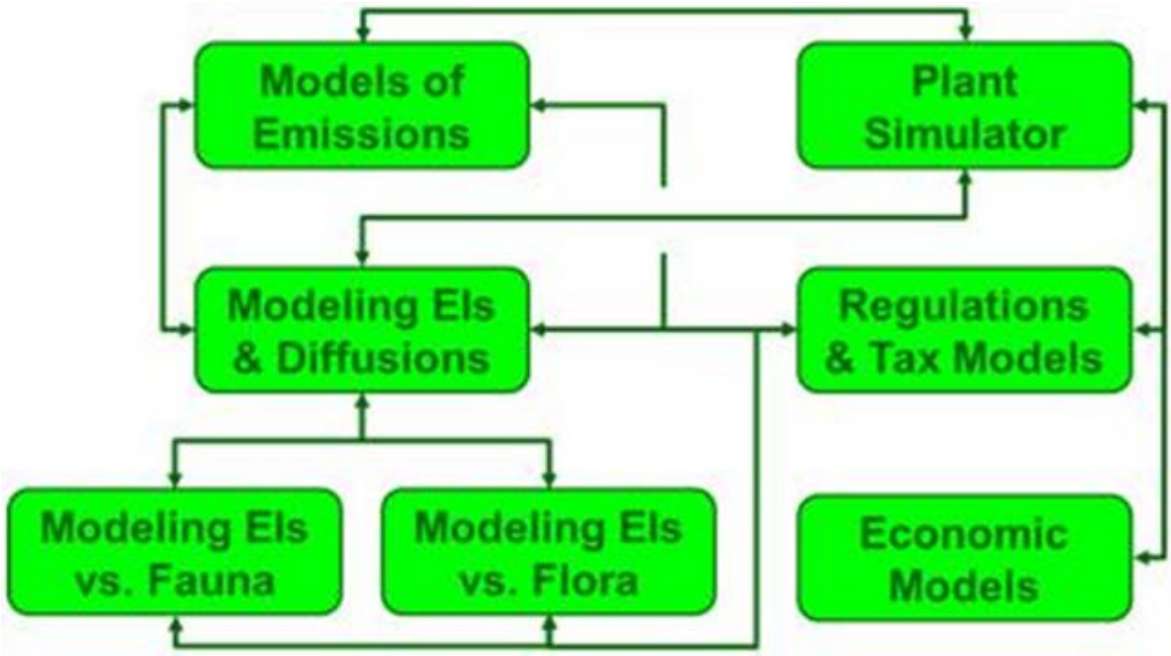


Figure 50 Models of the Power Plant EIs on the EMF

The author has been developing models to simulate the whole process and to address, in comprehensive way, the environmental impact over a complex framework; in this case it is proposed to study the Extended Maritime Framework (EMF) including air, underwater, sea surface, land & coast, etc (Bruzzone, 2014).

The author addressed this context in relation to operations with UxV (Unmanned multidomain Vehicles) that were integrated over an heterogeneous network (Bruzzone et al., 2016a); these studies could be useful also to develop future sensor networks with

autonomous capabilities to investigate on symptoms and alerts: e.g. sending an Autonomous Underwater Vehicle, AUV, to check diffusion of emission at different depth in the sea.

This section proposes a case study related to a power plant to be simulated to estimate its Environmental Impact by adopting a combined and innovative modelling approach. The motivation to conduct this scientific study is to develop a comprehensive model of EI such as emissions in marine environment of a specific Power Plant with multiple Gas Turbine, therefore it is evident the possibility to adapt approach to many different cases of Industrial plants. Among the possible alternative systems to be evaluated, the model should allow to support a feasibility analysis related to an innovative process that redirects CO_2 emissions in Marine Environment. These simulators are addressing a wide spectrum of applications such as industrial plant engineering, emergency management, industrial processes, joint operations, homeland security and defence, logistics, innovative technologies, autonomous systems and decision support solutions. Indeed, Simulation Team is a non-profit organization involving individuals and organizations where different modules such as Green Log, MOSES and IDRASS (Bruzzone et al., 2013) have been implemented. The author proposes here to adopt the MS2G paradigm (Modeling, Interoperable Simulation and Serious Game) that allows to combine different models by adopting simulation interoperability standards and to guarantee the MMI (Man Machine Interface) through the Serious Game approach. Indeed, Serious Game, by immersive technologies and properly design representations, is able to improve usability and understanding for simulation users through a physical and emotional engagement.

In a different case study, the author analysed a Power Plant Emission within a special CAVE (Cave Automatic Virtual Environment) developed ad hoc by Simulation Team in the frame of above mentioned MS2G solutions. This CAVE is named SPIDER (Simulation Practical Immersive Dynamic Environment for Reengineering) and is able to support distributed interactive simulation by combining continuous modelling of hazardous material spills and contaminations of air and soil with discrete event simulation about plant and autonomous asset behaviours (Bruzzone et al., 2016b).

7.1 Simulation Models

The simulation to be developed in this research track adopts the HLA standards for interoperability (Kuhl et al., 1999); this approach enables the possibility to create a Federation of simulator that interoperate, with different kind of models within the same context such as continuous simulation, discrete event simulation, combined simulation and system dynamics (Zacharewicz et al., 2005).

The author is currently combining different models addressing the different elements to be simulated, as proposed in Figure 50, using different simulation techniques for reproducing plant operations, emissions, diffusions, EIs impact estimation and costs and regulatory analysis. Indeed, continuous simulation of emissions and diffusions in the marine environment are combined, for instance, with discrete event simulation of plant processes and system dynamics related.

In order to complete successfully the Validation, Verification and Accreditation (VV&A) of the Simulator the author addresses different aspects and develops the corresponding models as summarized in the following:

Plant Simulation:

The model of the plant and its operations is a crucial part of the simulation and should be based on a technical process (Ylén et al., 2005); adopting MS2G paradigm it is therefore possible to include a simplified plant meta-model during preliminary tests and experimentations. This approach allow to speed up the development and VV&A as well as reduce the computational efforts for applying DOE (Design of Experiments) for optimization (Montgomery, 2008).

On the opposite, further investigation on optimized configurations is carried out substituting the meta-models with detailed plant simulator within the High Level Architecture (HLA) federation.

7.2 Modeling Different Power Plant Emissions

The plant emissions should be identified and specific models should be developed to estimate their nature and flow rates (Bottenheim, 1982; Lefebvre, 1998); for instance it should be possible to estimate the quantities of CO2 and other components dispersed in regular configuration within the environment, modelling the relationships among emissions and different plant configurations; these models should consider the emission nature as well

as the related characteristics under the different operational modes of the plant and along the years.

Modelling the EIs and their Diffusion in the EMF:

The diffusion models should consider boundary conditions (e.g. temperature, wind, current, etc.) as well as release methods to estimate the diffusion of the emission in the Extended Maritime Framework (Moussiopoulos, 1990); these components should also take care of modelling the interaction of the EI within the sea water, terrain and Air in EMF and the model should estimate how much part of them dissolves in water and how much part still remains in it.

An appropriate model should take into account the diffusivity phenomena, the interactions with the electrolytes contained in the environment (e.g. seawater) as well as the relevant equilibria of dissolved chemical elements. The boundary conditions from this point of view represent crucial factors: for instance, the effect of tides and currents affect the concentration profiles along the coast and in the deep sea and should be estimated by proper models.

In similar way it is necessary to consider medium and long terms of EI dispersed in the different EMF domains according to thermodynamics of vapor-liquid equilibria.

7.2.1 Models of the EI impacts on EMF Flora

These models should cover the impacts of different EIs and emissions on the flora in terms of health status within the Extended Maritime Framework (Aleem, 1972; Suresh et al., 1993; Ou et al., 2016). For instance, it should be necessary to develop models able to foresee

the CO2 concentration in water and its effects on algae population evolution, growth, reproduction as well as on the potential changes in their biological processes.

7.2.2 Models of the EI impacts on Marine Fauna

The adaptability of the EMF fauna to EI is another crucial component to be modelled and one of the most challenging in terms of environmental sustainability and eco-compatibility (Aleem, 1972; Suresh et al., 1993; Ou et al., 2016).

For instance, a concentration map of emissions in water will be related to their biological effects on different living species to ensure the respect of the marine ecosystem. As for Marine Flora, these models should estimate the changes on growth, reproduction and biological processes concerning vertebrates and invertebrates and the impacts that these changes might have on other symbiotic species, humans included.

7.2.3 Economic Models

The economic models should deal with estimation of profits and costs related to different plant solutions and operational models, reproducing dynamically the market evolution and potential trends (Benz et al., 2009). Risk reduction strategies aiming at reducing frequency or mitigating the magnitude of the impact on the environment can be categorized as engineered active and passive; managerial/procedural; inherent (Palazzi et al., 2015). The estimation of fixed costs related to different plant configurations and/or systems and subsystems will be required to analyze the different solutions, therefore it is also possible

to adopt a reverse engineering approach to estimate the threshold levels for feasibility of different solutions.

7.2.4 Modeling Policies, Taxations, Rules and Regulations

The Rules, Taxations and Regulations should be included in the model in order to estimate the taxes and fees related to different plant configurations and operational modes (Rafieisakhaei et al., 2016); in addition, this allow to estimate the dynamical respect of threshold levels and policies along the plant life cycle; it is important to outline that these aspects deal with International and National regulations and the related models should be tailored for the different areas and the structure of the models should allow to change these conditions and parameters in order to reproduce different scenarios. These elements are today particularly significant in order to understand the feasibility of plant refurbishments and changes according to economic advantages and compliances with existing laws and best practices. It is even fundamental to evaluate the effective advantage in terms of emission calculation in the environment and the regulations to be considered for the project feasibility.

7.3 Outline of the architecture

The general architecture of the model includes different simulators federated together each one including some of the above-mentioned models; the relevant simulators are shortly introduced in the following:

VAED (Virtual Aided Engineering & Design) is a combined simulation (continuous and discrete event simulation) that reproduce the power plant principal and secondary systems

as well as auxiliary plants and related processes, including thermodynamics and chemical reactions (Bruzzone et al., 1997). IDRASS (Immersive Disaster Relief and Autonomous System Simulation) is a MS2G environment combining discrete events and continuous simulation originally devoted to reproduce fall-out and spin off of hazardous material in industrial plants; this system could be tailored to reproduce dynamics of emissions and diffusion into the EMF during regular operations (Bruzzone et al., 2016b). GREENLOG PORT (Green Logistics for Ports) is a hybrid simulator allowing to consider the different EIs and to combine them based on a hierarchical structure (Bruzzone et al., 2010); the model has been developed for analysing Port Logistics and Processes, including ship emissions in air and sea and could be adapted to address this specific case study. MOSES (Modelling Sustainable Environments through Simulation) is a model based on system dynamics able to reproduce the impact of actions over an urban environment that could consider the EIs of different Power Plant configurations according to human, economic, environmental and social sustainability (Bruzzone et al., 2013). JESSI (Joint Environment for Serious Games, Simulation and Interoperability) is an interoperable simulation environment applied several time to the EMF (Bruzzone et al., 2016a); currently some kinds of marine fauna have been already successfully introduced (e.g. birds and sea mammals) and the models of marine flora and fauna could be introduced in this simulation; in addition it could be possible to reproduce and to estimate capabilities, costs and effectiveness on the use of AUV (Autonomous Underwater Vehicles) and UAV (Unmanned Aerial Vehicles) as solution to monitor and investigate the environmental impacts.

These simulators can interoperate and are integrated also with other solutions devoted to improve usability and VV&A through innovative MMI such as:

SPIDER (Simulation Practical Immersive Dynamic Environment for Reengineering) is an innovative Interactive CAVE (Cave Automatic Virtual Environment) developed by Simulation Team able to immerse multiple decision makers and/or scientists into a complex interoperable simulation. The basic configuration is compact (just 2m x 2m x 2.6m) and could be installed within a standard High Cube Container; SPIDER is fully compatible with any interoperable simulator and it has been already used to carried out experimentations with IDRASS and JESSI, is interactive through touch screen technology and it is fully immersive including sound and motion. ARTEM (Augmented Reality TErrain interoperable Module) is an interoperable HLA module designed to be integrated in a MS2G systems.

The results of the simulation are dynamically presented over smartphone and mobile devices providing them to the user in real-time and geo-referenced framework (Bruzzone et al., 2016b).

7.4 Applicative Case Study

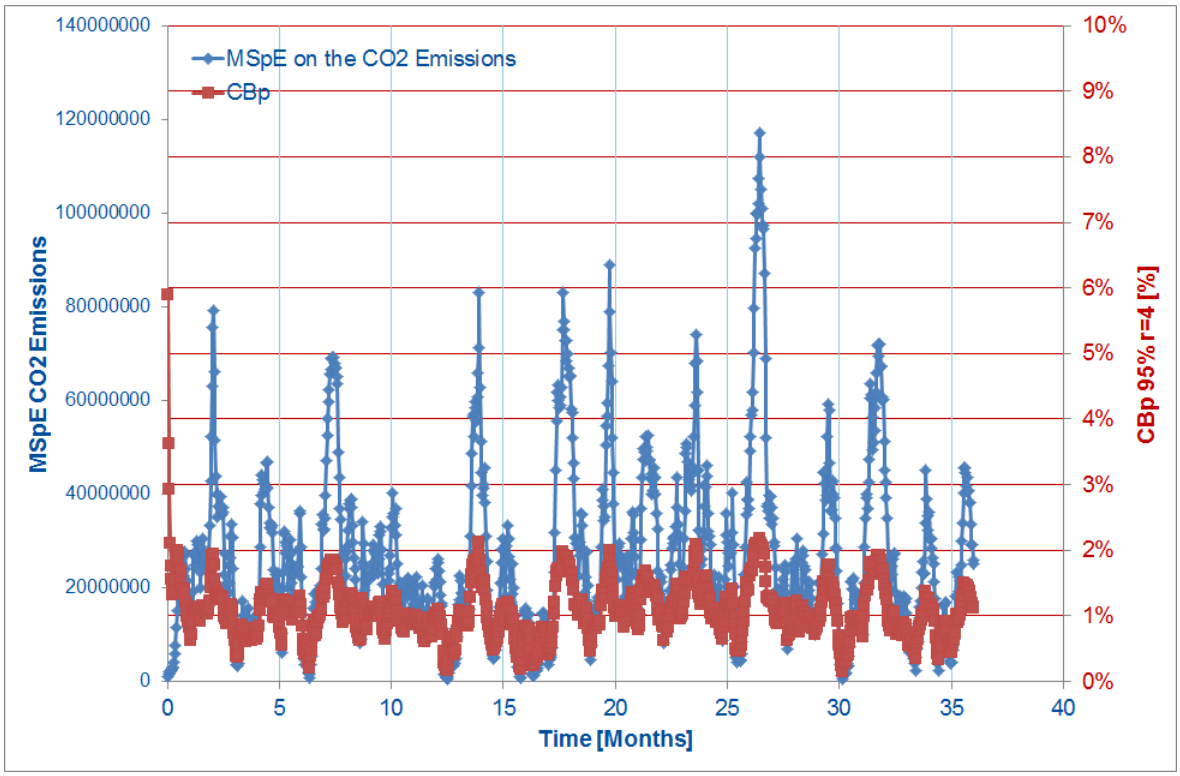


Figure 51 ANOVA on CO2 emission for this case study

Preliminary results on experimental error estimations due to the stochastic factors related to CO2 emissions are reported in Figure 51; the time evolution of the MSpE (Mean Square pure Error) is proposed as ANOVA (Analysis of Variance) in order to conduct the dynamic VV&A on the simulator (Bruzzone et al 2016a); this approach allows to estimate its confidence bands expressed by the following relationship:

$$MSpE(t,r,j) = \frac{\sum_{i=1}^{r}\left[Y_{j,i}(t)-\bar{Y}_j(t)\right]^2}{r-1} \quad (1)$$

where MSpE(t,r,j) is the mean square pure error of j-th target function at t time with r replications, r is the number of replications obtained by running the simulation on same

boundary conditions by changing only the random seeds, j is the j-th target function (in the proposed case emissions of CO2) and Yj,i (t) is the value of the j-th target function on the i-th replication carried out by the simulator at t time.

Moreover, $\bar{Y}_j(t) = \frac{\sum_{i=1}^{r}[Y_{j,i}(t)]}{r}$ and $\bar{\bar{Y}}_j = \frac{\int_{t_s}^{t_e}\frac{\sum_{i=1}^{r}[Y_{j,i}(t)]}{r}dt}{t_e - t_s}$, where $\bar{Y}_j(t)$ is the average value of the j-th target function over r replications carried out by the simulator at t time, $\bar{\bar{Y}}_j$ is the average value of the j-th target function over *r* replications carried out by the simulator along the whole simulation and t_e,t_s are the ending and starting time of the simulation.

$$CB(t,j) = +2t_{\alpha,r-1}\sqrt{MSpE(t,r,j)} \tag{2}$$

$$CBp(t,j) = \begin{cases} \bar{Y}_j(t) <> 0 & \frac{CB(t,j)}{\bar{Y}_j(t)} \\ \bar{Y}_j(t) = 0 & \begin{array}{ll} \bar{\bar{Y}}_j(t) <> 0 & \frac{CB(t,j)}{\bar{\bar{Y}}_j(t)} \\ \bar{\bar{Y}}_j(t) = 0 & 0 \end{array} \end{cases} \tag{3}$$

CB(t,j) is the confidence band amplitude at t time for j-th target function and CBp(t,j) is the confidence band amplitude expressed in percentage respect average value of the j-th target function at t time.

The analysis has been conducted by using a simplified meta-model in VAED and confirms good level of experimental error and confidence band even after few simulated months of operations; obviously these results cannot be generalized depending on the scenario adopted for the operational use of the Power Plant, but the set of tests could be easily repeated to update the analysis.

7.5 **Outcomes**

The approach proposed guarantees the possibility to investigate the impact of different aspects related to plant engineering solutions as well as to operational models to understand the effects of these elements on the multiple layers (e.g. air, water, flora, fauna, social, economic) of the Extended Maritime Framework, This represents a first step towards the development of an experimentation on a more extended case study.

The author completed the identification of models and simulators to be used as well as the overall architecture.

In the future, this modelling approach will be used to conduct experimentations for investigating the most effective solutions for CO2 storage taking into account their environmental impacts on ground, sea and air factors and also considering their sustainability in terms of economic aspects and technical reliability.

8 Intelligent agents & interoperable simulation for decision making in joint operations

This section proposes an innovative interoperable federation developed for addressing strategic decision making on multi-coalition operations, whose architecture integrates several different simulators in HLA and is open to be operated in different modes, from stand-alone basic installation to fully integrated with entity-based simulations.

The simulator uses Intelligent Agents, to reproduce human behaviour and human factors, as well as discrete event simulation paradigm into virtual and constructive environments.

The section describes the models as well as the approach to address this problem; some experimental results related a realistic scenario are proposed as well as the different solutions adopted to support Commander engagement in using this kind of simulation.

Currently most of existing humanitarian and normalization operations are carried out by international organization; in facts today most of the military operations carried out overseas have to face interaction with civilians in different roles, such as refugees, immigrants, internally displaced persons, etc. (Main 2009; Bruzzone, Sokolowski 2012); the dimension of the situations to be addressed as well as the socio cultural economic context are so big that it is pretty common to operate by multi coalition with specific goals and interests that interact in the same area by involving entities such as United Nations, NATO, EU, Nations (e.g. Russia, China), Red Cross, Red Crescent Moon etc.

In these contexts, the human factors are often the main aspects to be addressed as happened in recent scenarios such as Libya, Afghanistan, Syria (Johnson et al. 2008, Bellamy & Williams 2011; Dewachi et al. 2014). For instance, the HBM (Human behaviour modifiers) that include fear, fatigue, stress, aggressiveness as well as need for food, water, health care and security, strongly influence the behaviour of both military forces (including also opposing force) and population, both locally and domestically (Gartner & Segura 2008; Kreps 2010; Bruzzone et al. 2013b). The rational and emotional behaviour of the people within the scenario is another crucial element (Bruzzone et al. 2011a). Examples from operations in different cases from piracy to CIMIC (Civil Military Cooperation), from country reconstruction to Disaster Relief confirms that the use of simulation integrated with human behavioural models are key issues for proper decision making (Bruzzone et al.2010, 2011b).

Simulation Team developed since 2001 intelligent agents to be used to address these issues; in particular IA-CGFs (Intelligent Agents Computer Generated Forces) have been successfully applied over a wide spectrum of applications and tailored for different socio-cultural frameworks (Bruzzone 2013a). In this research IA-CGFs have been used to address specifically multi-coalition joint operation and to create an interoperable simulation over this mission environment as done for other cases (Bruzzone et al. 2012, 2018e).

Due to these reason, an interoperable simulation integrating all these elements represents a significant tool for supporting decision making on issues related to human factors within complex scenarios.

The author proposes here these models in relation to a project devoted to create a simulator for immersing a Commander into a comprehensive scenario where human factors are decisive (Bruzzone et al. 2014a, 2015).

The research is related to SIMCJOH (Simulation of Multi Coalition Joint Operations involving Human Modeling) project that was developed under coordination of Simulation Team, DIME, Genoa University in cooperation with CAE, Cal-Tek, MAST, MSC-LES University of Calabria and Selex (Bruzzone et al. 2014a) and cosponsored by Italian MoD.

Figure 52 SIMCJOH_VIS Main Window. Presents the situation and the events to the User and all major commands

This section's focus is on SIMCJOH federation and in particular on SIMCJOH VIS (Virtual Interoperable Simulator) and SIMCJOH VIC (Virtual Interoperable Commander) that are

the two main simulators, developed by Simulation Team, for directing the whole simulation and managing the human factors.

8.1 Human behaviour modelling

To model complex operations involving population and human factors is a challenge and requires the tailoring of HBM (Human behaviour modifier) for the specific scenario; indeed in this case the mission environment is driven by SIMCJOH project and focusing on Middle East; as matter of facts, the research team had experience in tuning HBM for many different regions including this context (Bruzzone et al. 2014a, 2018d).

Originally SIMCJOH was devoted to carry out R&D activities with the aim of understanding at which extent interoperable simulators are effective and efficient within a multi-coalition context for supporting the Commander and his Staff in addressing and solving specific problems strongly dependent on human factors.

Indeed Modeling & Simulation make possible to recreate complex scenarios and to carry out "*what-if*" analyses with the aim of evaluating the effectiveness of several alternatives (Course of Actions, COAs). By this approach it is possible to develop training aids and even briefing supports able to immerse the Commander and his Staff into a virtual scenario driven by the Intelligent Agents (IA) that evolves dynamically and react to the decisions and actions in real time or fast time.

For this scope SIMCJOH was developed as an interoperable Federation able to operate in multiple modes; for instance, SIMCJOH could run in stand-alone mode for being used

simply and quickly by the Commander on his own laptop to improve effectiveness of briefings when he is assigned to a new command and/or in a new geopolitical area.

As an alternative, SIMCJOH could be fully federated through HLA integrating entity level simulation, scenario generators, communication network models, C2, becoming a dynamic element of a CAX (Computer Assisted Exercise) that introduces strategic issues and human factors within a large scenario.

SIMCJOH adopts the innovative MS2G paradigm to guarantee easy distribution of the simulator, the main simulator is able to interact through web and it is designed for being visible within a browser (Bruzzone et al.2014b).

Such concepts benefit of previous experiences in web based simulation (Bruzzone et al. 2008, 2009a, 2009b) that are adopted in SIMCJOH_VIC; this is an interoperable serious game devoted to immerse the Commander into a 3D environment synchronized with SIMCJOH scenario evolution and it is able to provide video streams from UxV point of view; this approach allows to overpass traditional serious games and to adopt new uses for these applications such as crowdsourcing and virtual experiencing on complex systems (Rayburn 2012; Tremori et al. 2014).

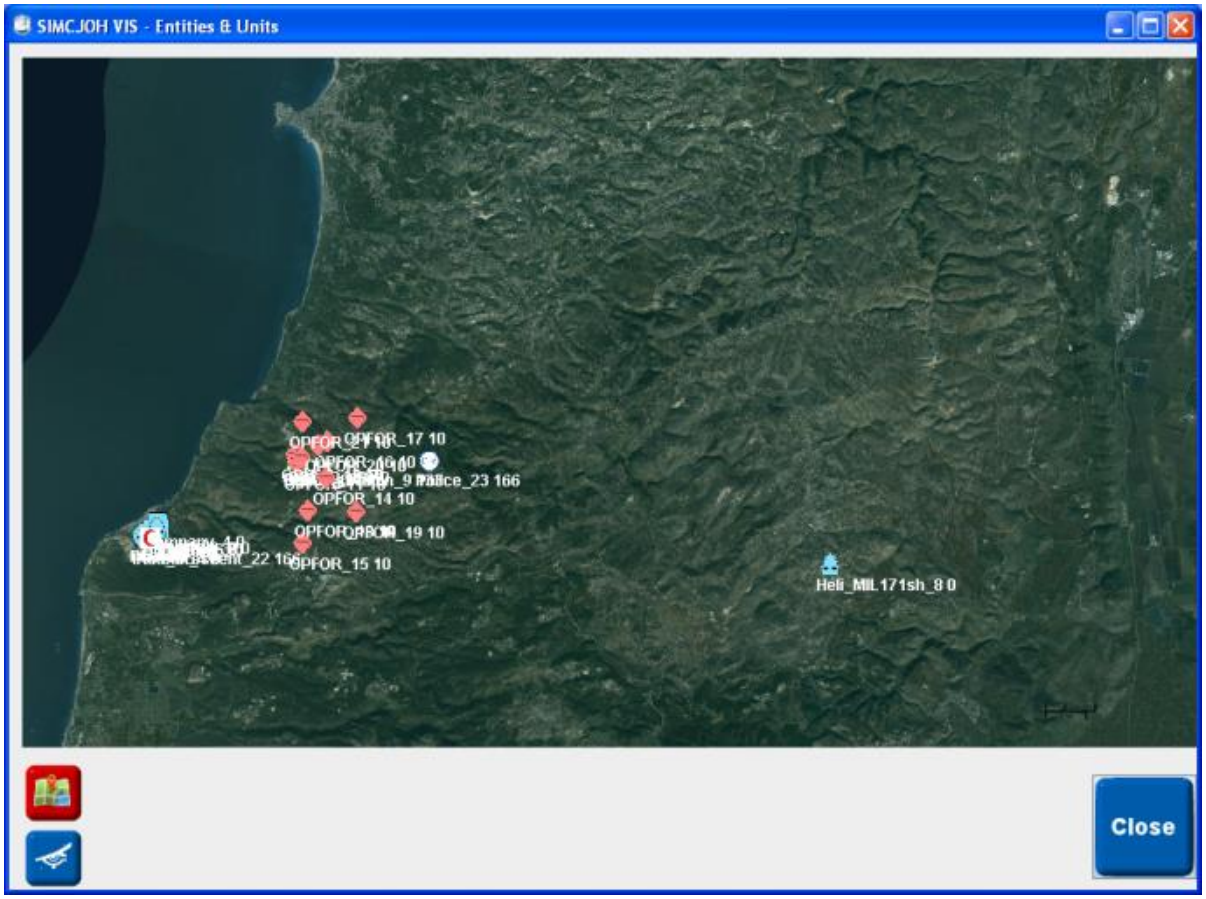


Figure 53 **SIMCJOH VIS Tactical Representation Window**

The author developed the main simulation engine for this scenario as an innovative model, defined SIMCJOH_VIS (Virtual Interoperable Simulator).

SIMCJOH VIS is a stochastic discrete event simulation driving events, human behaviours, population reactions, unities and events over whole SIMCJOH federation.

SIMCJOH_VIS simulator is a specific NCF (Non Conventional Framework) of IA-CGF which drives the units and active entities within SIMCJOH federation, in charge of reproducing emotional, rational and social behaviours of entities and units and, even, to interact with the Virtual Assistants that are virtually reproducing Commander Staff.

Indeed, the Virtual Assistants are proactive IA proposing to the Commander problems and open issues, as well as possible solutions in terms of alternative COA; these IAs execute Commander's decision; in addition to that they actively react to Commander requests.

These processes are simulated considering stochastic durations and workload required to identify the problem, prepare the alternatives and present them to the Commander as well as to assign operational orders.

Most of the events generated and managed by SIMCJOH_VIS are presented by other federates (e.g. tactical situation, C2 representation, virtual immersive 3D environment), therefore to support easy quick stand-alone mode SIMCJOH_VIS proposes also its own intuitive dynamic graphics (see figure 1); in this case the crisis representation, the boundary conditions (e.g. daylight, sensor view, population status) as well all the events are visible on the GUI; the events are represented as pop up while a sequential storyline is generated stochastically in consistency with the simulator during the evolutions of the events.

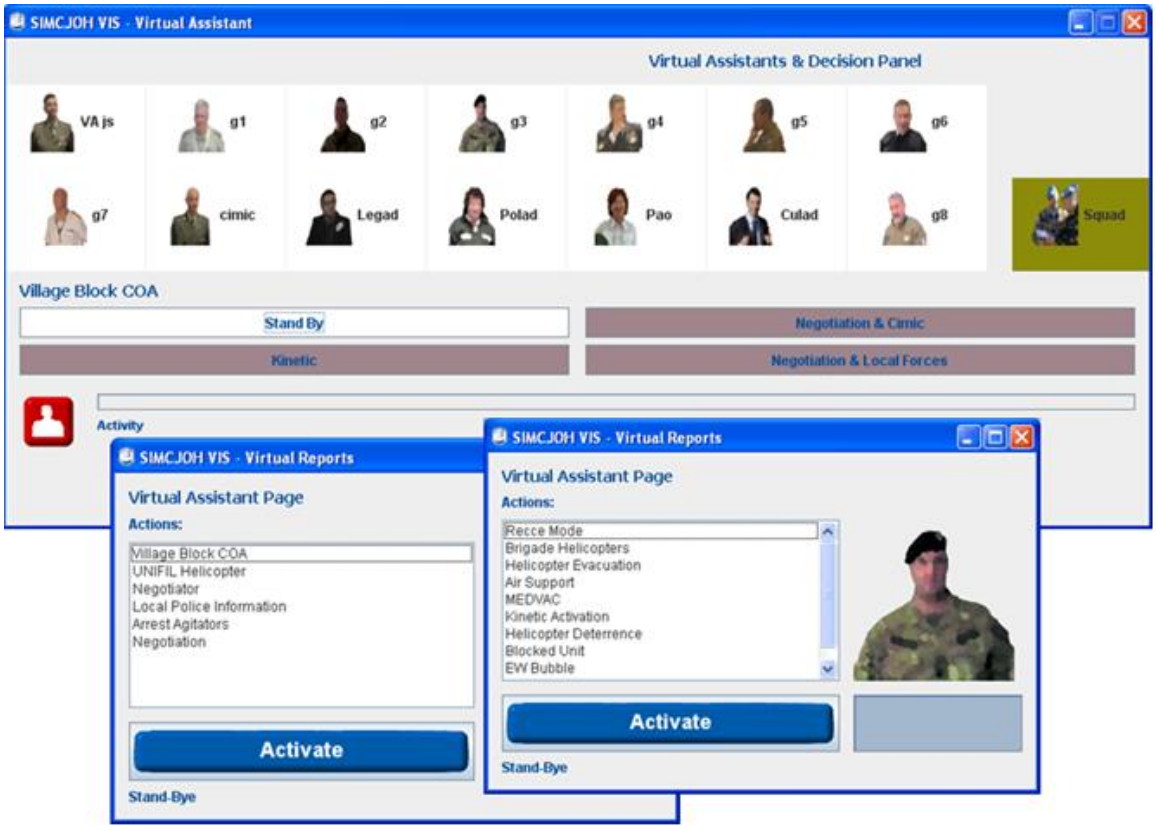


Figure 54 SIMCJOH_VIS Virtual Assistants

8.2 Simjoh_VIS Features

SIMCJOH_VIS includes Entity Simulation Models and it allows simulating different kind of entities and units; these entities could be represented over a very basic tactical framework within SIMCJOH_VIS even if tactical and virtual representations are supported by other simulators federated in HLA SIMCJOH Federation.

SIMCJOH_VIS considers the use of entities for many different assignments including "force to force" actions, therefore these agents drive also other entities such as paramilitary units, ambulance and NGO, demonstrations etc. The simulated entities are characterized by several

information including among the others HBM. Indeed Figure 55 presents a very basic tactical representation of the on-going situation.

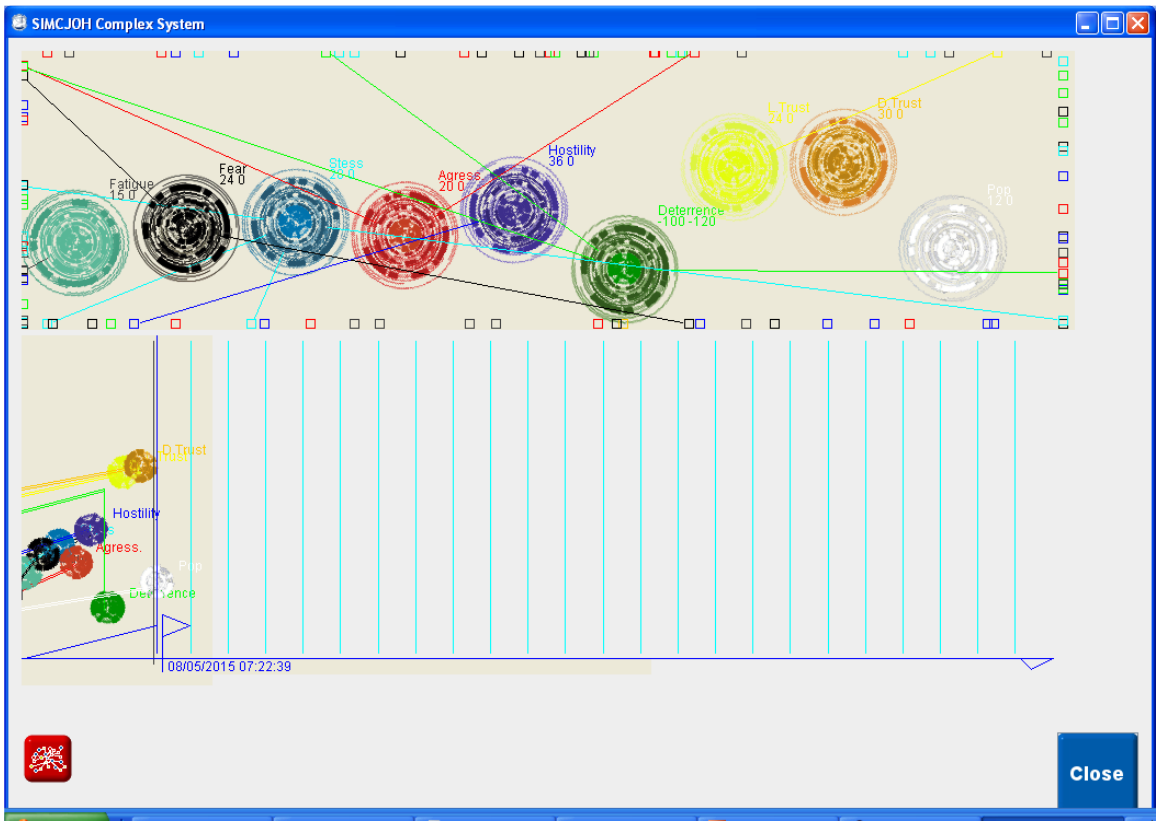


Figure 55 *Graphic Dynamic Representation*

In Figure 54 is presented a Virtual Assistant (VA) and the possibility to request him actions and reports. It is possible to access to SIMCJOH_VIS Virtual Reports generated by the VAs and then, eventually, to decide what COA apply in reference to current situation.

8.3 Human behaviour modifier

As shown in Figure 55, SIMCJOH_VIS proposes the dynamic evolution of HBM along each simulation run; these objects corresponds to the main human factors and their evolution is

driven by IA-CGF; the events dynamically generated are creating also opportunities for decisions, autonomous reactions and emerging behaviours.

In in the upper part of Figure 56, the graph proposes the different variables as ball elements; these include from left to right:

Fatigue - Fear - Stress - Aggressiveness - Hostility - Deterrence - Local Trustiness - Domestic Opinion - Demonstration Size.

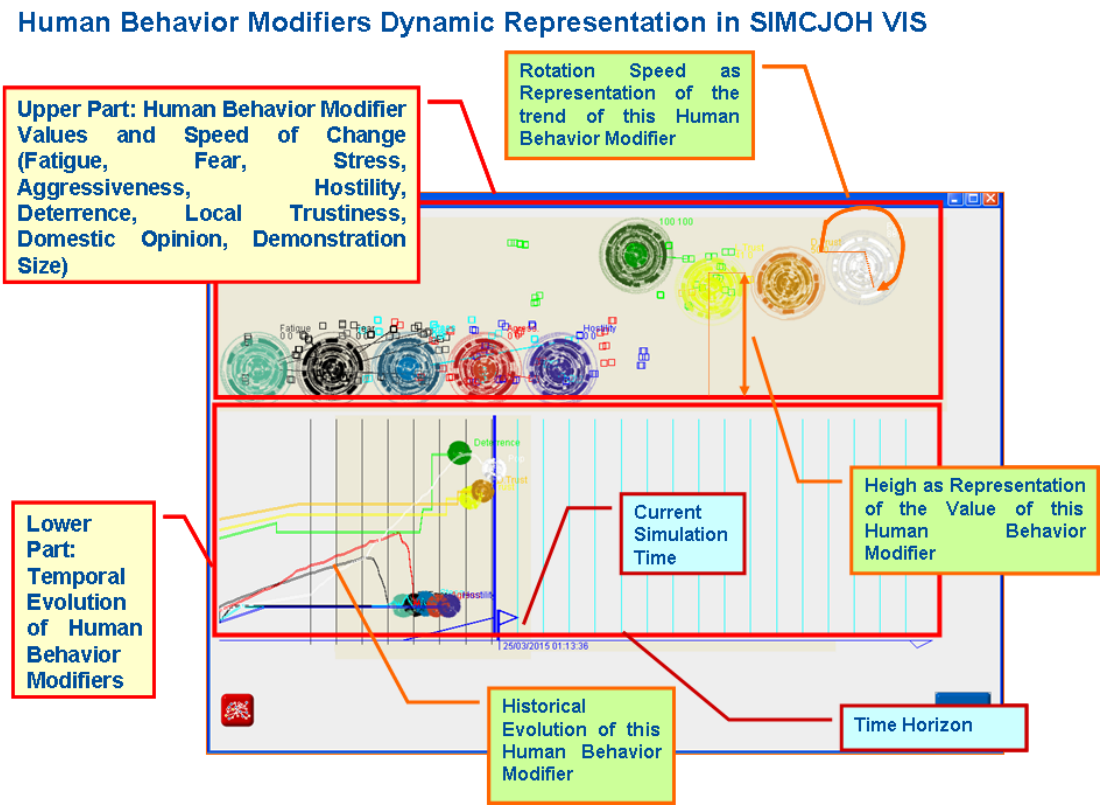


Figure 56 *HBM Dynamic Representation*

Each ball element rotates based on its change rate and moves up and down based on its intensity; their values are pure numbers corresponding to a relative scale going from zero to 100 for Fatigue, Fear, Stress, Aggressiveness, Hostility; the relative scale used moves from

minus 100 to plus 100 for Deterrence, Local Trustiness, Domestic Opinion in terms of positive and negative attitude respect opposite size; Demonstration Size is scaled between zero to 1000 people.

Small Squares are generated and moved, in this figure, toward the different Human Behaviour Modifiers (e.g. stress, fatigue, etc); each of these squares represents an event or action that is increasing/decrease these modifiers.

Vice versa, in the lower part of the window the graph presents the same factors as balls, but it reproduces their behaviour in terms of temporal evolution along simulation time horizon as well as their trends; this supports the users in understanding the situation evolution, in identifying the critical changes in population behaviour corresponding to crucial events as well as the effects of his decisions. The Temporal evolution of target functions is also available for analysis (ASCII file in format CSM).

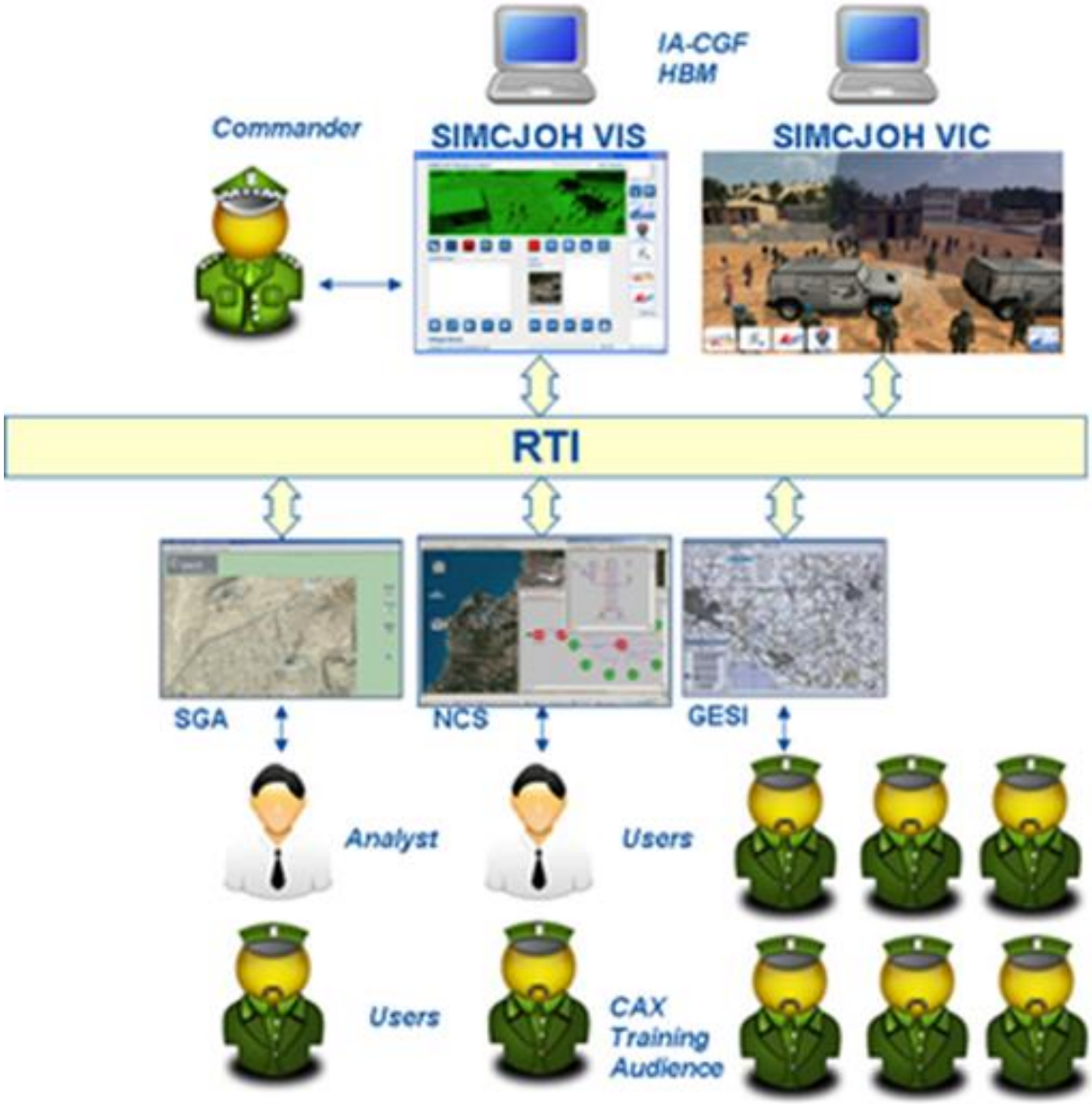


Figure 57 *SIMCJOH Federation in full operative mode for CAX*

8.4 Interoperability

SIMCJOH_VIS operates as main element of SIMCJOH Federation and drives the whole scenario evolution; currently it was experimented mostly by operating with Pitch and Mäk RTIs, but also portico was tested; SIMCJOH_VIS was used mostly in Windows

environments, even if limited tests were conducted also on Linux and Mac. The SIMCJOH architecture is proposed in Figure 57.

The proposed simulator allows changing the configuration to allow proper initial setting in reference to eventual limitation of other federates,

HLA Configuration for this simulator includes:

- Federate Name
- Federation Name to Join
- RTI Engine to be used, currently supporting Mäk, Pitch and Portico
- IP Address
- Port Number
- Synchronization Point Mode and Number of Federates to wait as well as Synchronization Object Name
- Date and Time to use as offset for Simulation in HLA mode

In order to guarantee the interoperability among the different simulators, it was introduced a specific interaction defined as PlayerMessage to be made available in SIMCJOH format and in JSON (JavaScript Object Notation) format.

Both formats could be activated concurrently generating in HLA multiple messages for same event.

SIMCJOH_VIS includes other possible elements devoted to change Simulation Setup through the following variables:

- Duration of the Simulation [h]

- Offset that represent the starting time and date for the simulation in standalone mode.

8.5 Scenario

The context for testing SIMCJOH is identified in Middle East area over an hypothetical country, named Eblanon, where United Nation (UN) are active by a multi-coalition mission; the case study address the Commander of an Italian Army Brigade that is responsible for the area; the scenario includes events that, despite their small entity, have strategic relevance for the contingent and for multicoalitions; in this research is proposed a MEL/MIL (Main Event List/Main Incident List) developed by the author where a squad is blocked into a village by demonstrators requiring them to surrender their weapons; considering the UN mandate and ROE it is evident the critical impact of such decision; the simulator regulates this scenario adding many possible elements such as presence of international and/or local media, mobile coordination, presence under coverage of insurgents and/or snipers, accessibility to the area by helicopters, previous CIMICs (Civil Military Cooperation) in the village and their success rate, etc. Based on this scenario and on available resources the Commander could decide different COA, eventually tailoring them, while the IAs driving his staff (e.g. J2, J3, CULAD, POLAD, PAO etc.) support his decisions and direct the simulation evolution in similar way other IAs rule other parties (e.g. population, local authority, religious authorities, bordering countries, insurgents, etc.). The nature of this area of Middle East is pretty interesting considering the large differences in terms of ethnics, religion, social status, education, etc. In addition to these elements the presence of different players (e.g. Local

Authorities, Health Care, Red Crescent Moon, Other Coalition Partners having specific equipment, etc) forces the Commander to understand the correlations among different actors.

8.6 Experimental Analysis

SIMCJOH_VIS was subjected to formal, informal and dynamic VV&T (Verification, Validation and Testing); the model was presented and discussed with military experts involved in the specific scenario used for the experimentation; in addition, the data collected by multiple simulation runs were used within ANOVA (Analysis of Variance) by applying Design of Experiments (Montgomery 2008). In facts, the SIMCJOH experimentation was focusing on identifying the behaviours of target functions mapped by the simulator; this analysis represents an example of how Design of Experiments and Sensitivity Analysis allow evaluating the impact of independent variables on the target functions. Concerning the experimentation execution and the simulation results, an example of techniques and methodologies to be used for studying results consistency is proposed in this section. In particular Mean Square pure Error and Sensitivity Analysis are carried out for the different alternatives.

The analysis of MSpE (Mean Square pure Error) is a consolidate techniques supporting ANOVA both in terminating and steady state simulations; indeed MSpE measures 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 bands. Vice versa Sensitivity Analysis allows identifying the influence of different parameters or choices respect specific target functions; for sensitivity analysis hereafter are synthetized the main alternative COAs:

- Stand By COA: The Commander requests to wait for further evolution
- Negotiation & CIMIC COA: Using CIMIC and previous activities in the area to negotiate with locals about stopping the crisis
- Kinetic COA: The Commander requests to prepare military units in stand by status to force the demonstrators to desist by applying controlled deterrence
- Negotiation and Local Forces COA: The Commander requires support to Local Police Authorities for negotiating with the population and solving the problem.

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

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

MSpE allows to quantify the experimental error due to influence of the stochastic components respect the required replications or durations for obtaining a stabilization, making possible to estimate the confidence bands on the different target functions.

For instance, considering the Aggressiveness Level of Population related to the 4 different commander decisions, the MSpE was computed by carrying out replicated runs over the same boundary conditions.

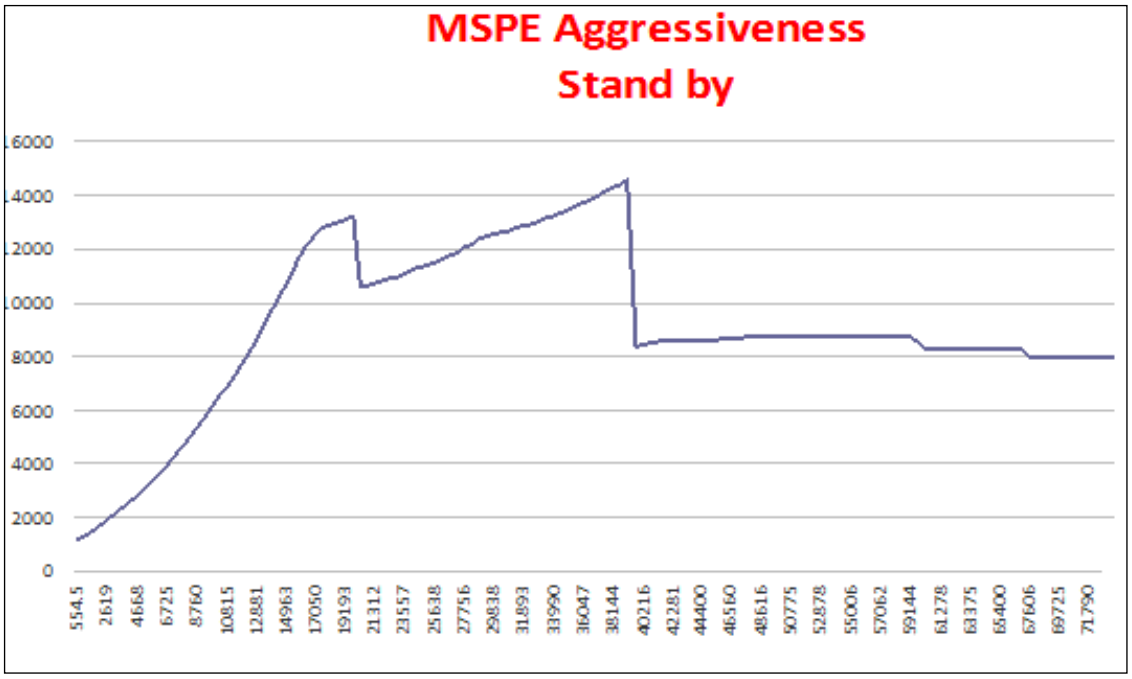


Figure 58 Evolution in case the Commander applies "Stand By COA"

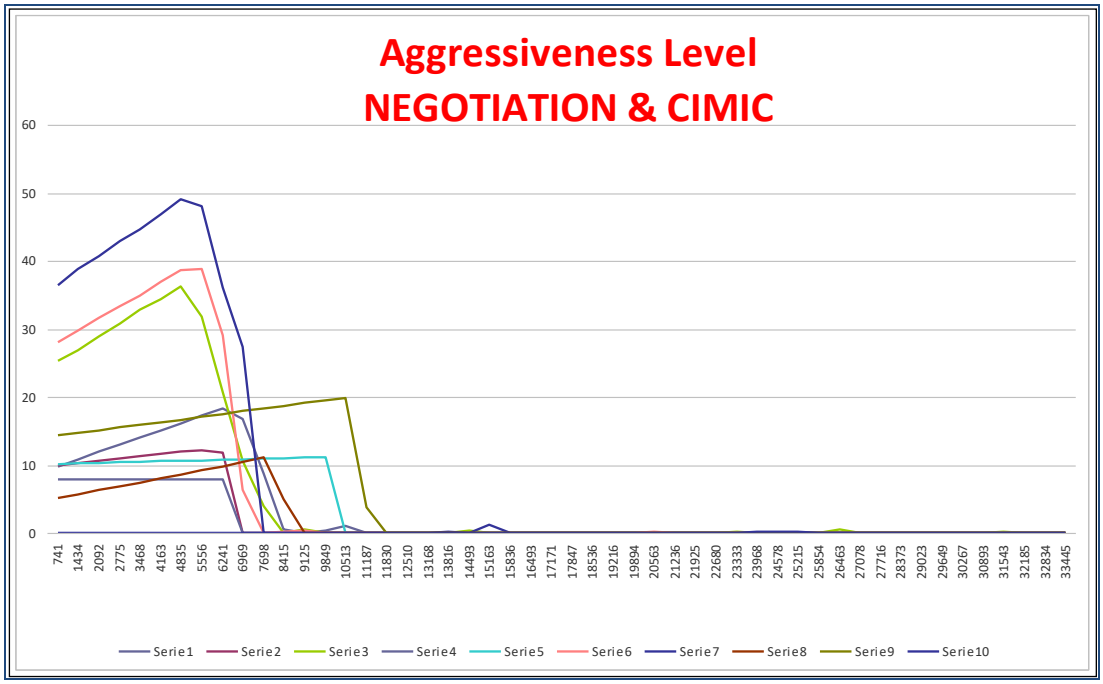


Figure 59 **Negotiation & CIMIC: Results of Different Runs**

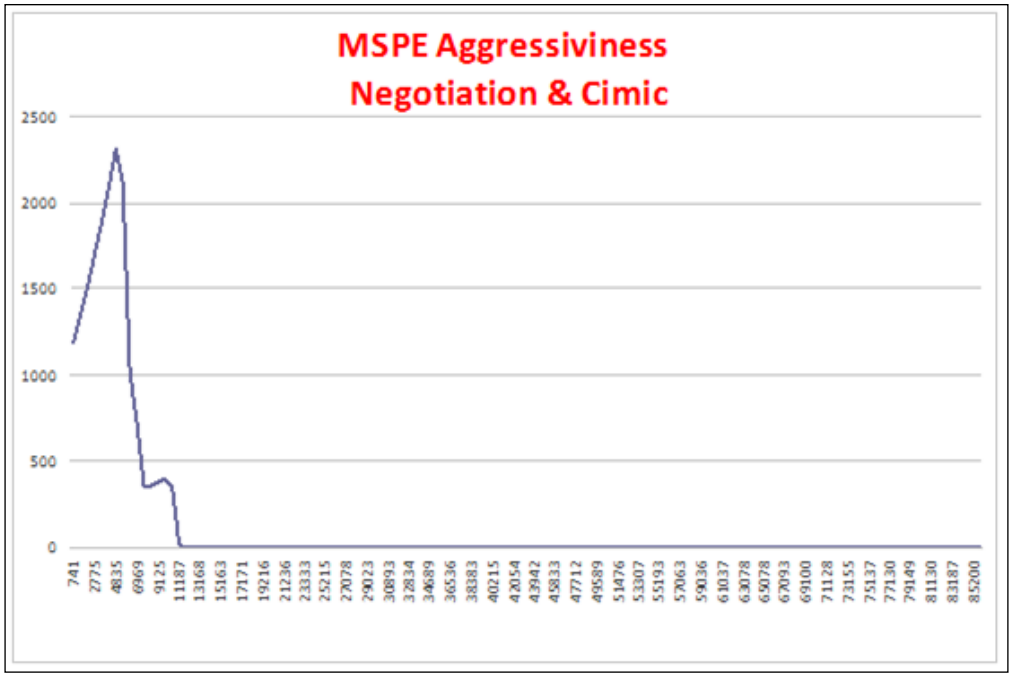


Figure 60 **Option 1 – Negotiation & CIMIC COA - MSpE**

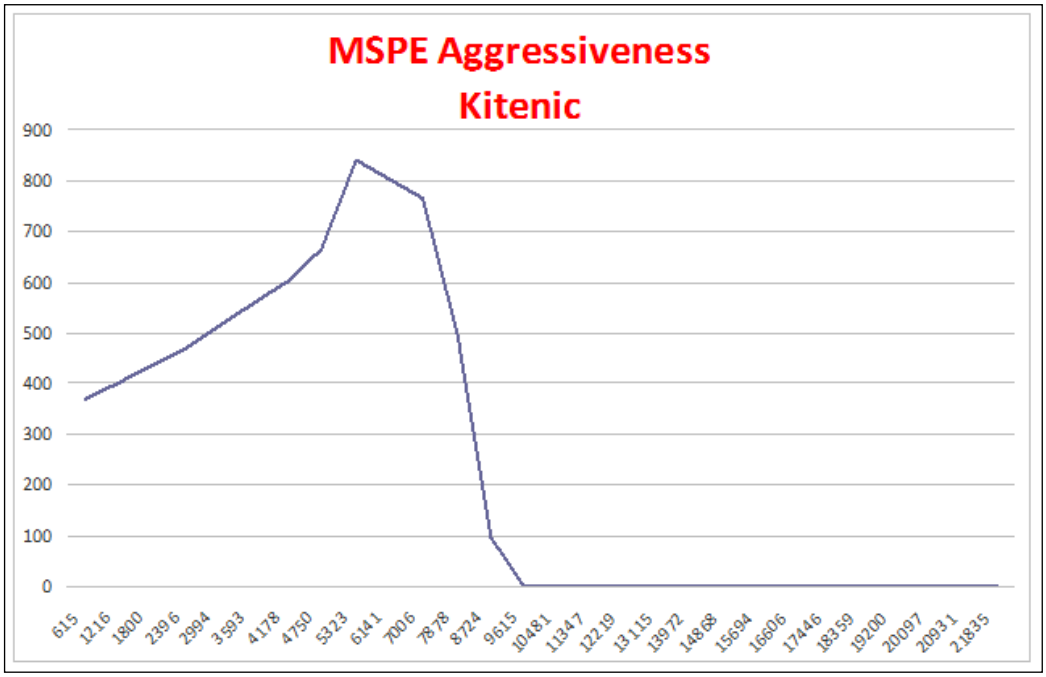


Figure 61 **Option 2 – Kinetic COA: MSpE**

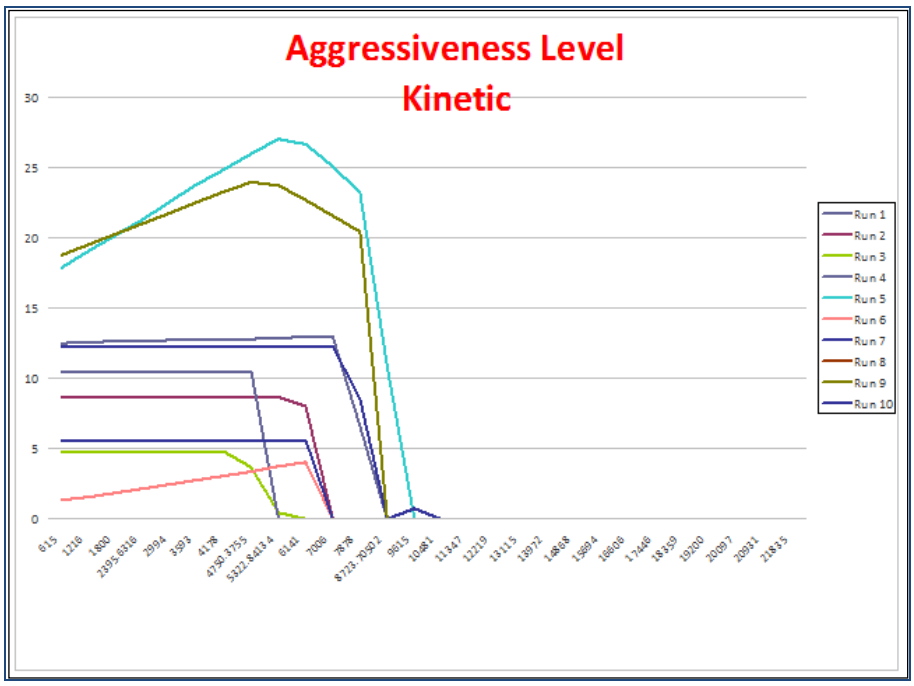


Figure 62 **Option 2 – Kinetic COA: Replicated Runs**

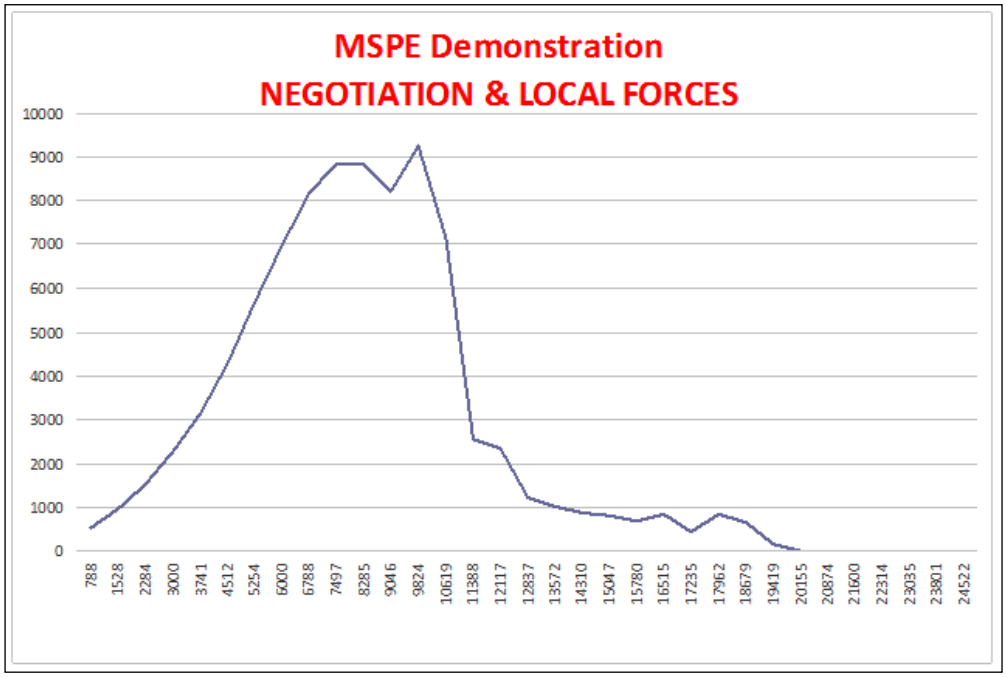


Figure 63 **Option 3 – Negotiation & Local Forces COA: MSpE**

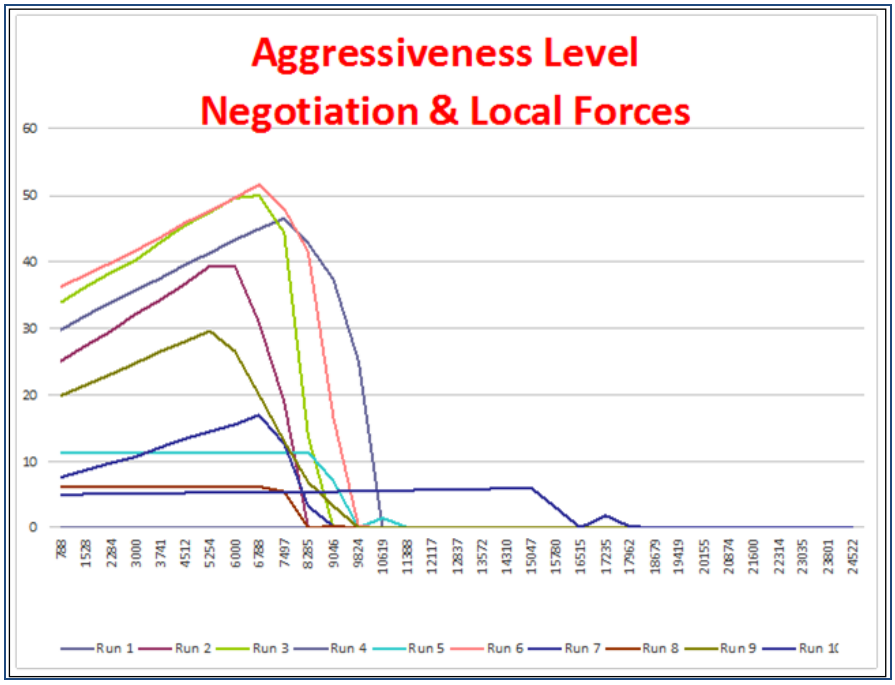


Figure 64 **Option 3 – Negotiation & Local Forces COA: Replicated Runs**

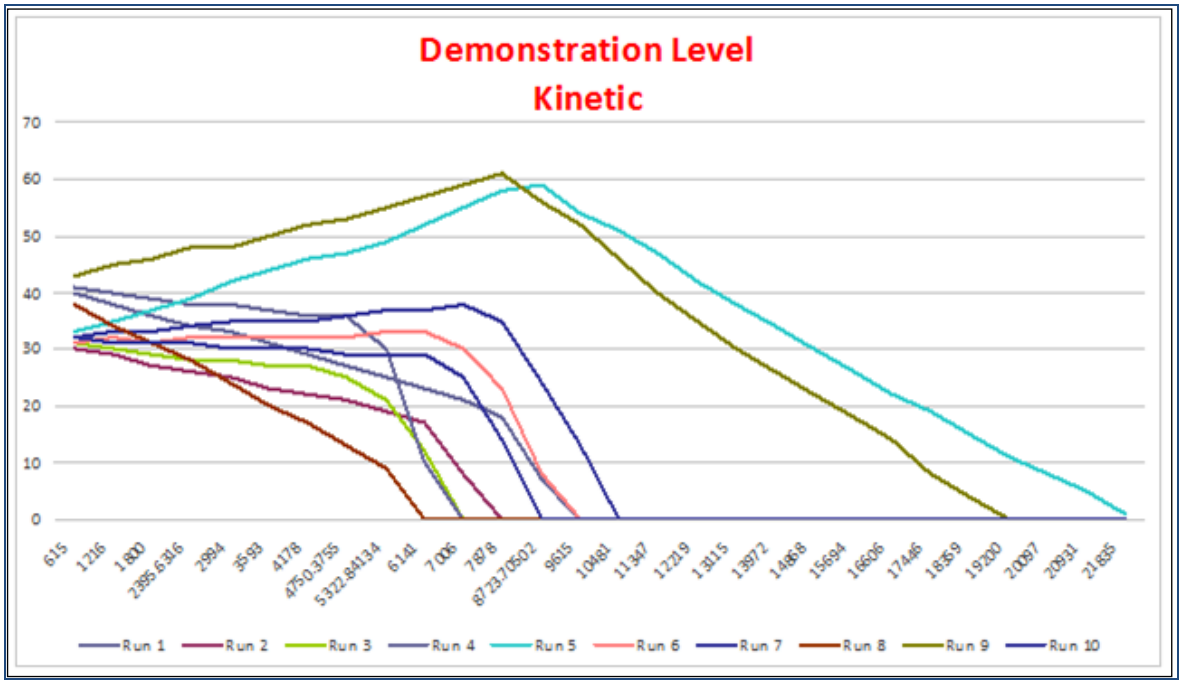


Figure 65 **Option 2 - Kinetic COA: different End States – Demonstration Size**

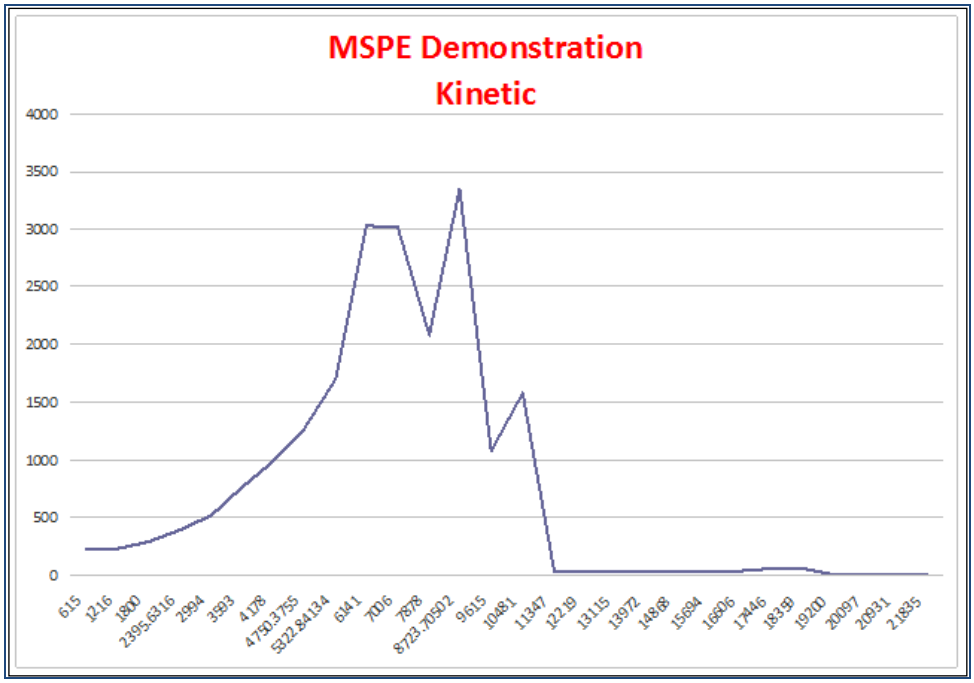


Figure 66 **Option 2 - MSpE among Converging Runs – Kinetic COA**

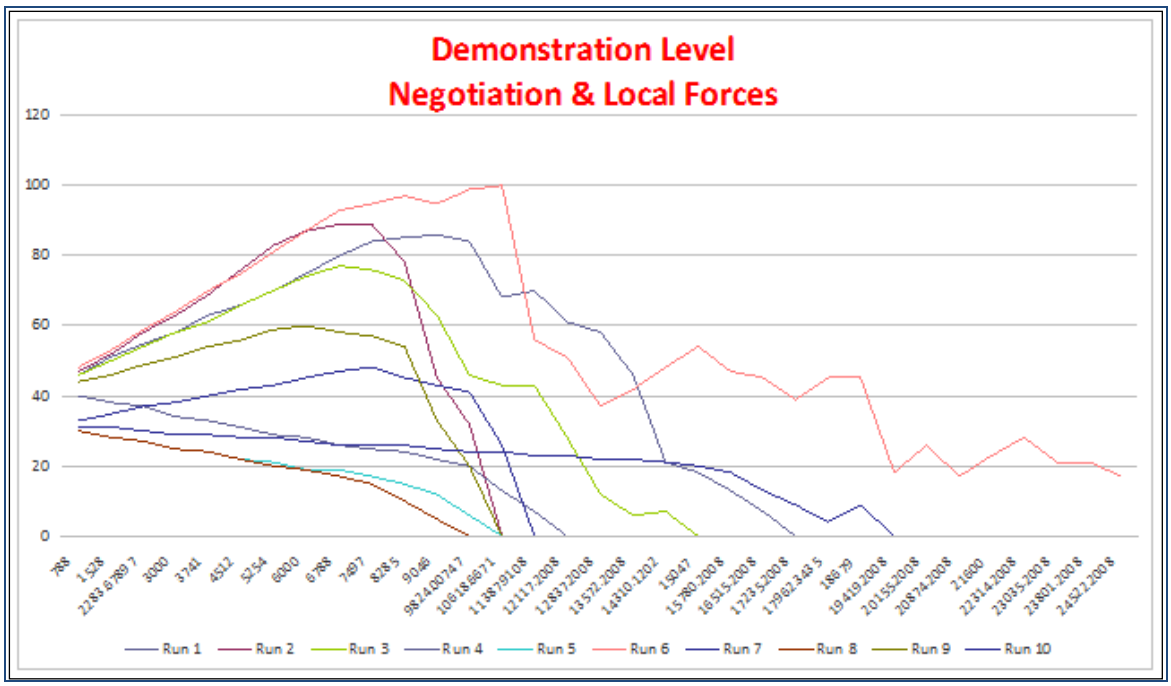


Figure 67 Option 3 - Negotiation and Local Forces COA – Size of the Demonstration

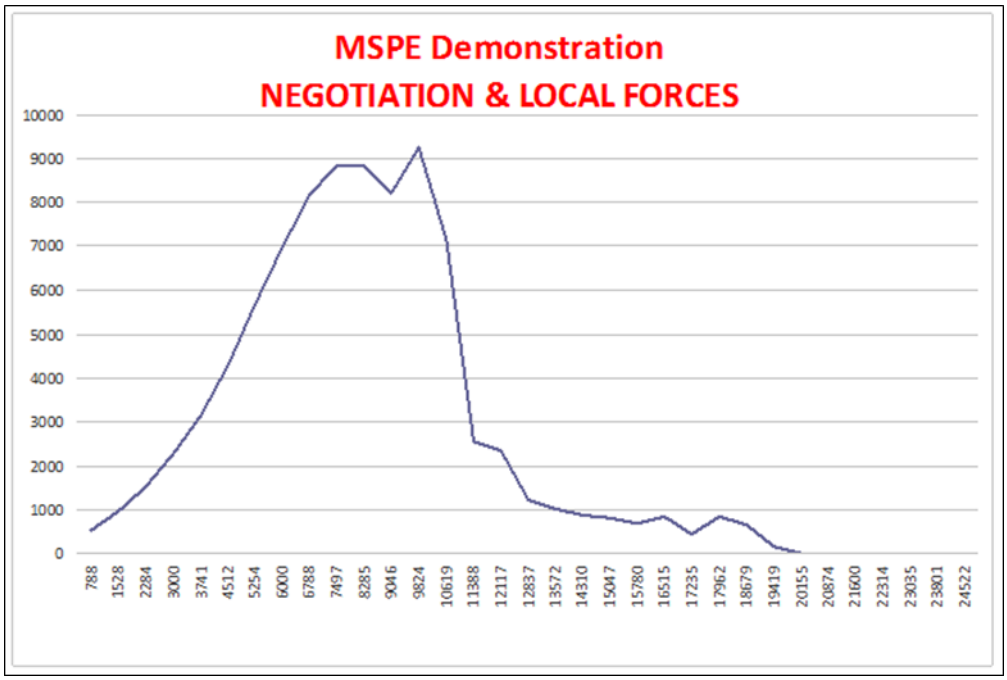


Figure 68 Option 3 - Negotiation & Local Forces COA –Demonstration Size MSpE

In the figures above, multiple runs are compared for the different decisions; indeed, different end states could be obtained due to stochastic components corresponding to the risk element; therefore, based on MSpE, the final achievements are consistent.

A further analysis has been conducted by measuring the Demonstration size along the simulation respect the four main different COAs corresponding to Commander.

The results of the MSpE considering 10 replicated runs are proposed into the attached figures.

By applying Design of Experiments, it was completed a set of experimental tests for evaluating the influence of the independent variables respect the target functions; this Sensitivity Analysis is synthesized in Figure 69 and Figure 70, where the main alternative COAs are compared respect target function.

SIMCJOH_VIS was extensively tested federated with SIMCJOH_VIC and with other HLA Federates within SIMCJOH Federation including among the others: GESI, SGA, SC and summarized in terms of target function temporal evolution as proposed in Figure 71.

8.7 Outcomes

SIMCJOH_VIS (Interoperable Virtual Simulator) represents an important tool to create new dynamic scenarios for different applications: preparation and briefings related to new environmental conditions (immersion in new scenarios), training on the comprehensive approach, training, etc.

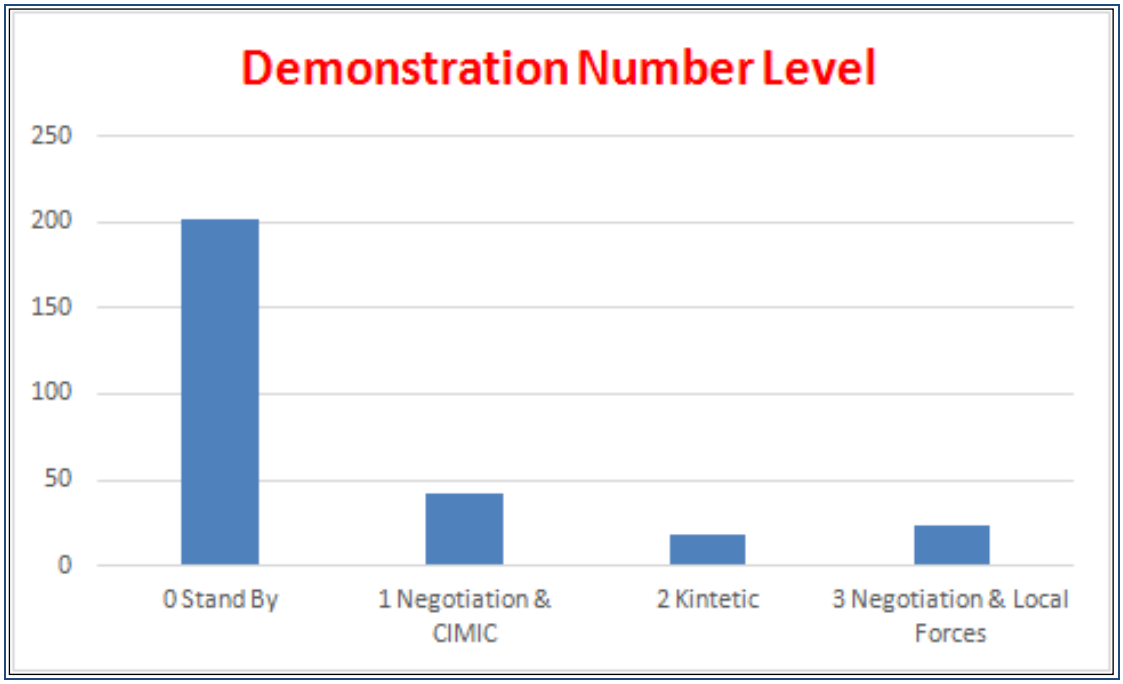


Figure 69 Main COA Decision Sensitivity respect Demonstration Average Size

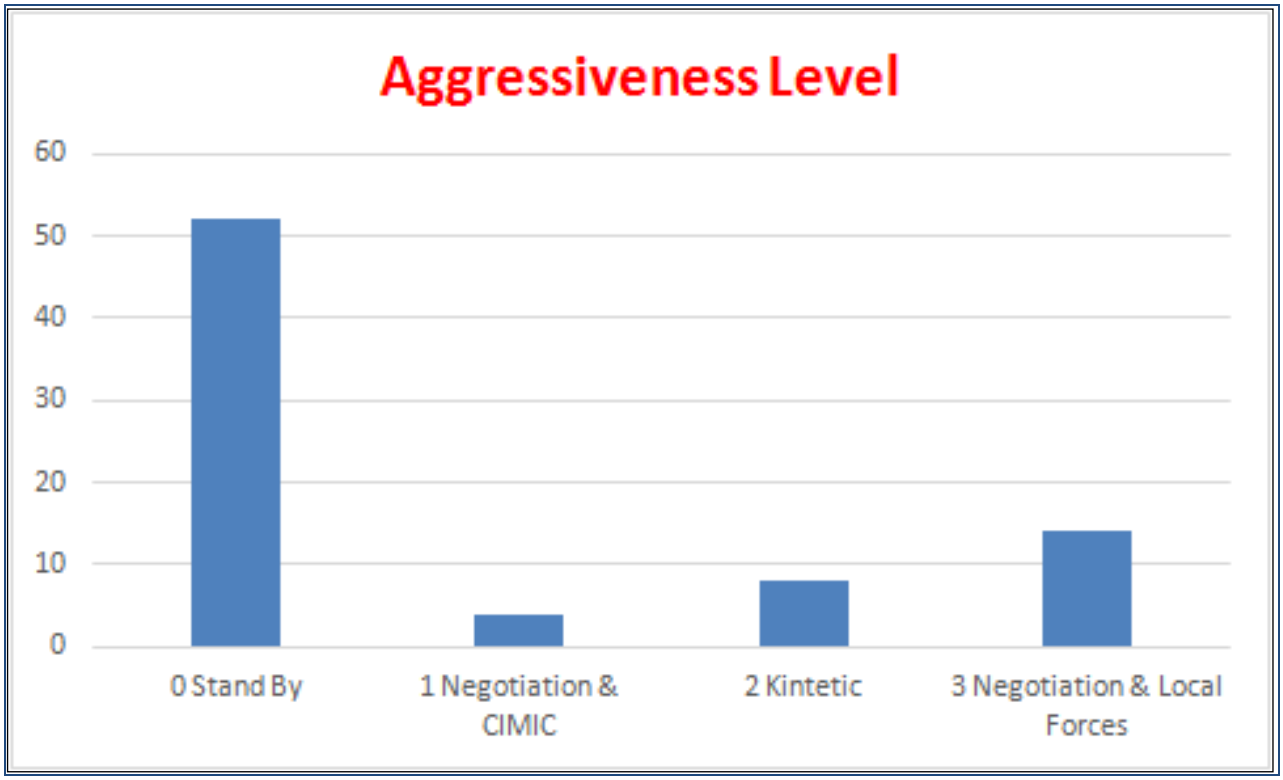


Figure 70 *Sensitivity of Main COA Decision on Aggressiveness Level*

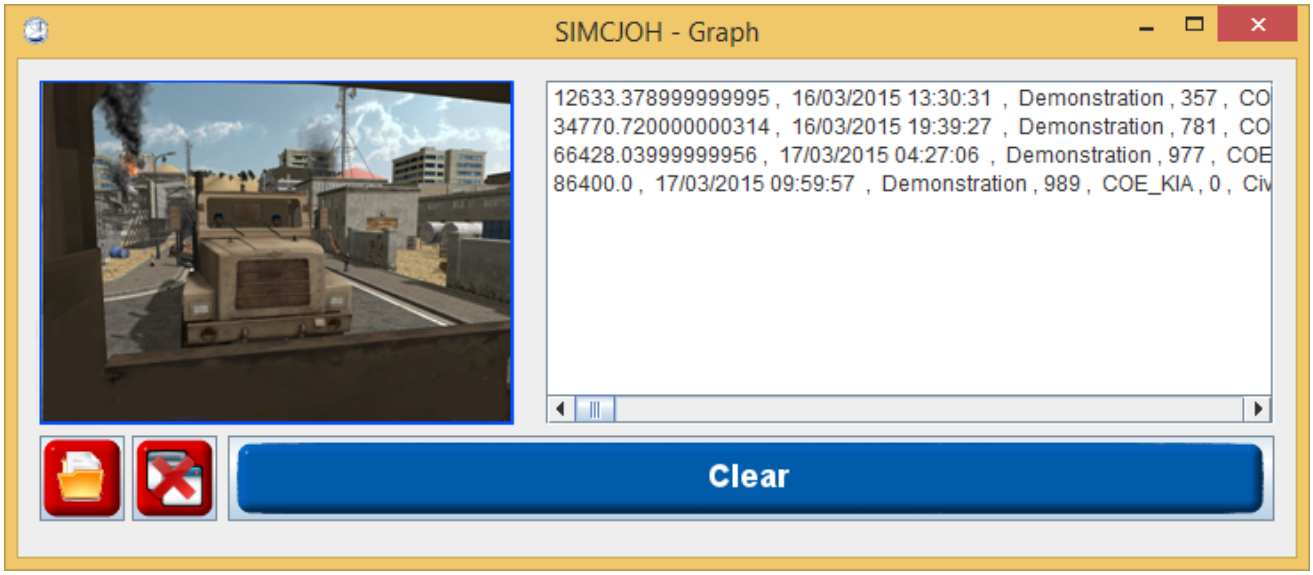


Figure 71 *Target Function Report*

The human models of SIMCJOH_VIS could be integrated with other scenarios, missions and operations where these aspects are important and may interact with other models and simulators. In fact, the SIMCHJOH_VIS is built for validating and experiencing the potential of a new generation of MS2G able to use human behavioural patterns and ensure interoperability with other simulators to recreate complex scenarios.

SIMCJOH_VIS is also further developable to create a training system for officers and government's decision/policy maker able to reproduce case studies and to provide an interactive environment to understand reactions and human factors related to decisions and events.

9 Modelling and Simulation for Space Applications

This thesis highlights the importance of Interoperable Simulation Systems as precious instruments to support and improve space exploration projects.

As matter of facts, one of the environment of the Extended Maritime Framework is Space. Space is fundamental to ensure the stability of the communications and impacts on every aspects on people daily life.

To give an example, let's think on how people relies on GPS for their daily movements; not to mention the importance of GPS for dynamic positioning of off-shore structures and supply vessels.

Having the capability to have a backup plan to avoid space systems shut-down is hence paramount. One of the most promising solution relies on microsatellites. The main idea is the quick deployment of a network of microsatellites to cover the gap left by an attack to regular satellites. But this is not their only application. Microsatellites are currently adopted to study the effect on microgravity on human cells, with the aim of acquiring knowledge for future human based space mission. M&S constitutes an excellent low-cost low risk environment for experimenting on the newly developed microsatellite platforms.

The capability of the space environment to alter the cells behaviour seems to be an opportunity for future researches in biology for diseases such as cancer.

This thesis investigates the potential of Modeling & Simulation to reproduce a virtual environment for biological researches and support Nano-satellite experiments in cooperation

among different stakeholders involved in a space mission, such as scientist, engineers and biologists.

The sphere of the human environment and exploration continues to expand towards space; there is a need to enrich the knowledge on the effect of the Sun and "space weather" to preserve the safety of the astronauts (Marhavilas 2004).

The space environment conditions are extremely challenging for human body, with microgravity condition joined to ionizing radiation sources including cosmic rays and solar particle events (SPEs) (Benton 2001, Townsend 2005). Several studies conducted on astronauts after they spent several months in space proved that an extended exposure to microgravity conditions are correlated with health problem, for example bone loss (Lloyd et al. 2008, Lang et al. 2004).

Despite the health of the astronauts, space environment capability to alter the cells behaviour seems to be an opportunity for future researches in biology, for diseases such as cancer.

This is proved by several studies, present in literature, describing experiments on microgravity devoted to gain insights into its effect on living organisms (NASA 2001).

Furthermore, several promising experiments have found some correlation with the behaviour of certain cells and bacteria and the simultaneous conditions of microgravity joined with ionizing environment. The experimental results suggest that cell development and proliferation is different in microgravity conditions and within ionizing environment (Massimiani et al 2014, Leys et al. 2009, Vanhavere 2008, Mastroleo 2009).

Some scientist supposes that microgravity conditions may give the possibility of developing tissues and biological samples in three dimensions as it happens within human bodies: analysing the experiments conducted in a cell cultures in a 1-g environment the proliferation is evolving only in two dimensions, this does not make them perfectly representative of what actually happens inside our body where the growth is three-dimensional. The same cell types in orbital systems highlights this substantial difference confirming that space is a unique and incomparable environment for biological research.

The reasons of this different behaviour have not yet been fully determined, but it is supposed to be correlated to a number of investigated factors:

- Interaction with terrestrial magnetic field: it could cause other effects in addition to those caused by microgravity (considering the nature of membranes which act as electrical capacity).
- Microgravity: this element generates different behaviours in biomedical samples between real and simulated microgravity; indeed in the ground simulators it is not possible to reach the microgravity levels common in low-Earth orbits (on the range of 109 - 105 g). By altering gravity, we are able to investigate partially these effects on biological systems related to the presence and reaction to this unique force. However simulating microgravity on Earth for more than several seconds is impossible with existing technology. By using spaceflights, we are starting to understand that not only gravity, but also the physical changes that occur in

microgravity conditions, may have effects on the evolution of species and their ecologies.

- Joint effect of microgravity and ionizing environment: the impossibility to reproduce the effects of microgravity in a laboratory (due to technological limits) does not allow to consider its combined interactions with ionizing radiations. In addition, the space radiation is different from the one that we normally experience on Earth, such as x-rays or γ-rays.

The combined effect could result in additional elements affecting the radiation hazard caused by exposure; these are usually acting by "changing of body systems functioning at all levels: from cellular up to organism". In facts the ionizing radiation exposure causes changing on body systems.

All these factors, combined with the reduction of costs in space missions, increase the interest of biomedical researches in using the space as a laboratory for its studies.

Simulation could guarantee a right first-time approach in setting up the experimentation & testing, helping reducing risk and cost issues.

9.1 Nanosatellites for biomedical experimentation

The world's first artificial satellite, the Sputnik 1, was put in space by Soviet Union in 1957. Since then, thousands of satellites have been launched into the space and are nowadays in orbit around the Earth (Lanius et al. 2013).

Last technological innovation, in use to support biomedical experimentations, is represented by CubeSat nanosatellite generation (Puig-Suari et al. 2001). These miniaturized satellites for space research, usually launched by a carrier rocket or launch vehicle are made up of multiples of 10 x 10 x 11.35 cm cubic units (Bouwmeester & Guo 2010). They have a mass of about 1 kilograms per unit and a Geocentric Orbit at Low Earth Orbit (LEO) altitude, usually <0.1 times Earth radius.

9.2 M&S supporting space missions

Space missions are extremely costly and dangerous and Modelling & Simulation (M&S) is extremely useful to support engineering and reduce risks; indeed M&S allows to evaluate feasibility of experimentation in terms of equipment and technical solutions (Baxter 2010). Decision makers as well as project leaders usually face limited resources and rigid time constraints for space experimentation and they need to test the feasibility of complex systems before realizing them in order to avoid unexpected problems. That's why M&S provides a strong support, particularly in the initial phase of a project giving to stakeholders a holistic view of the whole context (Montgomery 2000).

In other researches described in the sections of this thesis the author performed several studies on M&S reproducing complex systems behaviour in different fields including space (Bruzzone et al. 2016), logistics (Bruzzone et al. 2014), Intelligent Agent Computer Generated Forces (IA-CGF), disaster recovery in critical environment (Bruzzone et al. 2016 b), reproduction of intelligent behaviour (Wooldrige 1995, Bruzzone et al. 2015), data &

communications exchange among different entities (Bruzzone et al. 2013) and training (Bruzzone et al. 2011).

Despite all, these areas are really different one each other, they have a common line because they reproduce complex problems where non-linear functions lead often to counter-intuitive behaviours on the system itself that evolves dynamically along the simulated timeline. Furthermore, the M&S allow to simulate conditions and situations that are often impossible to be reproduced in experiments on the Earth, both for the costs and for technological complexities.

To this end, the author proposes a simulation devoted to investigate all the operations required for setting the real experimentation of Nano-satellite technology applied in space for studying the combined effect of microgravity and ionizing radiation on cancer cells affected by GBM (Glioblastoma Multiforme).

GBM is the most common form of malignant brain tumours with a median survival time of patients with less than one year. It represents 52% of all cases of primary brain tumour and 20% of all intracranial tumours. This type of cancer is actually treated by the best health facilities through the surgery and subsequent exposure to chemotherapeutic and radio therapies (Mahaley et al. 1989).

Because of its "multifaceted" nature, complete surgical tumour excision is often very difficult and sometimes impossible without permanent damage in the patient.

Because of the high incidence of this type of cancer and its characteristics it is necessary to deepen the knowledge of its pathogenesis by studying the behaviour in various environments

including the space. A better and detailed knowledge of cells behaviour affected by GBM, should lead to identifying the causes that generate it or pharmacological remedies to counteract their evolution and development.

For this reason, the basic idea is referred to the biological effects of ionizing radiation and microgravity that could increase the chances of success of treatments and biomedical applications.

9.3 Nanosatellites for space experimentation

In this paragraph the overall architecture and nature of the CubeSat Systems are described. Indeed, it is proposed a summary of systems, subsystems and components system that have to be considered for being simulated:

- Mechanical Systems and Structure: the satellite is made mainly of Aluminium 6061T6; it is usually considered, also in these nanosatellites, by using rapid prototyping design to adopt space qualified materials to build some structural components and to reduce its weight. Biological experiments should be hosted in special insulated containment module that are designed to be equipped with monitoring system.
- Observation System: an on-board observation system is required to monitor cell samples at various stages of the experiment.
- Thermal and Heat Exchange Systems: to keep alive the cells during all the mission phases in necessary to maintain a controlled environment (around 37 °C) despite the

space extreme variation in terms of temperature. The thermal control system consists of sensors, insulating material, heat exchangers.

- Ionization and Radiations Phenomena: to obtain accurate scientific results, experimenters must understand the radiation environment during the duration of the experiment. A micro-dosimeter is necessary to measure the amount of ionizing radiation that is absorbed by the samples. The number and type of micro-dosimeters will depend on the required accuracy.
- Microgravity Environment: In order to understand microgravity conditions during the experiment, researchers need to use different kinds of accelerometers, with accuracy and dimensions compatible with mission goals. In particular two kinds of accelerometers are used. One for high level of acceleration during the launch, the other to measure microgravity conditions.

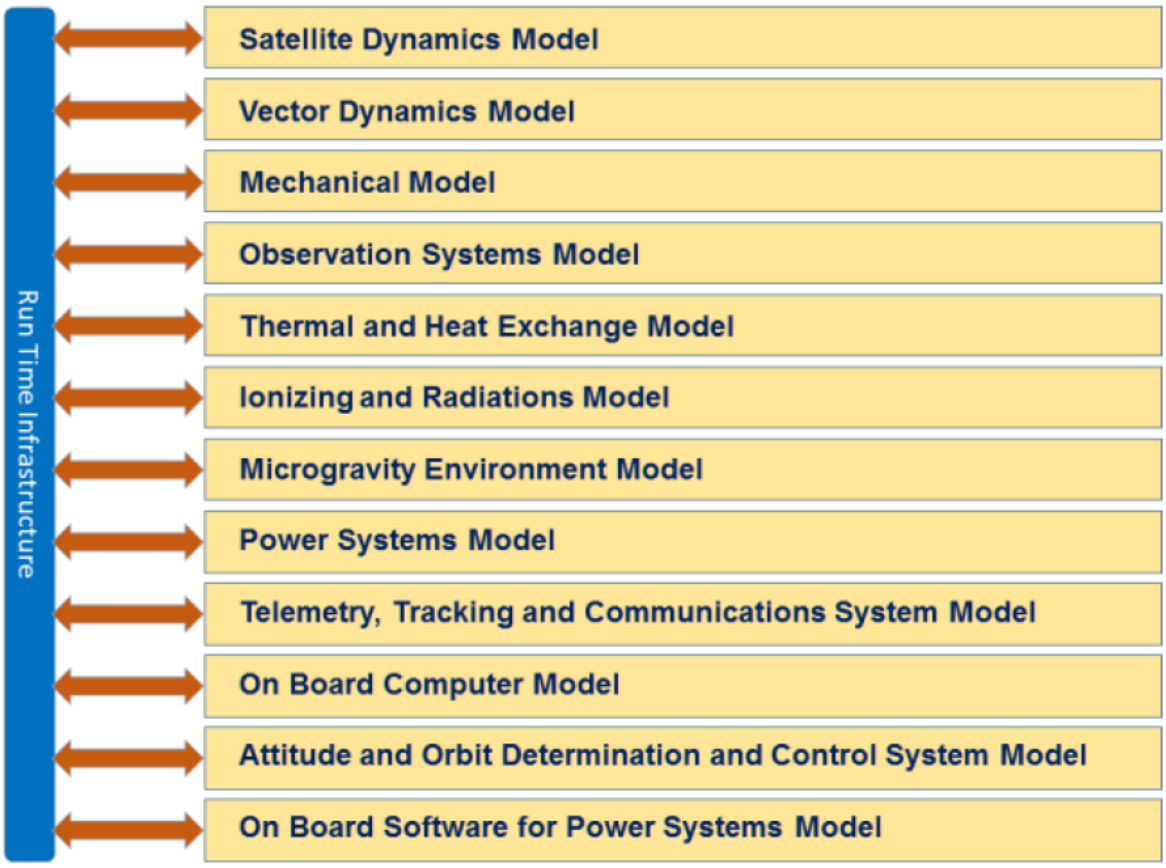


Figure 72 Space applications General Architecture

- Power Systems: an autonomous power system is needed to operate the whole systems including life support for keeping the cells alive during all mission phases. The nanosatellite uses solar cells and lithium batteries to provide power. The power is managed by a battery charge regulator. During the integration and launch phases the nanosatellite is turned off and for this reason an umbilical connection with the launch site will provide power to the payload before the satellite release in orbit. Different solutions for umbilical connection need to be analysed taking into account also the possible launch vehicle available.

- Telemetry, Tracking and Communications System (TT&CS): the TT&C act as the unique communication system once the SC is released from launch vehicle system. The TT&C communication uplink allow the mission control centre ground station to upload command sequences in order to program all the SC operations using a UHF/VHF radio link and also for the monitoring of the platform via dedicated Telemetry.
- On Board Computer (OBC): the On Board Computer act as the brain of the system coordinating the function of all the subsystems. The main features of the OBC include the presence of two independent, but cooperative cores: one low power consumption microcontroller for the general management of the satellite (payloads, TT&C, specimen status, retrieving of data from sensors); the second core is an FPGA (Field Programmable Gate Array) for implementing specific tasks or generic systems also with IP cores (Intellectual Property) of third parties.

  The OBC is provided with several sensors on board and a 9-degree IMU (Inertial Measurement Unit) made by 3 axes magnetometer, 3 axes accelerometer and 3 axes gyroscope.
- Attitude and Orbit Determination and Control System (AODCS): this module supports the in-orbit control of the satellite by using on-board sensors and actuators, support the orbit corrections, attitude and spin rate control with high accuracy to ensure the communications link and to properly analyse the results of environment monitoring system (e.g. radiation level). The AODCS controls also the positioning

of the satellite in the selected orbit, in order to understand the results from the micro-dosimeter according to the known radiation exposure levels.

- On Board Software for Power Systems (OBSW): this system is compatible with OBC hardware and is based on a firmware that could be updated in terms of functions along the mission if necessary.

9.4 General architecture and model description

M&S supports experimentation of space mission, giving the possibility to model the systems, subsystems and components and analyse interactions among them and biological samples.

The model is used to provide a measure of the resilience of the system to a hostile environment such as space, where reliability is challenging and it is necessary to evaluate redundancies, systems availability and capabilities.

Considering the flexibility demonstrated by the Intelligent Agents and Virtual Simulators developed within the MS2G (Modeling and Interoperable Simulation and Serious Games) paradigm (Bruzzone et al. 2014), the author decided to realize a federation to be applied to Space Experimentation based on this approach. The author benefits of the research team experience on past different simulators (Elfrey et al. 2011, Bruzzone et al. 2014) created for SEE/Smackdown initiatives including SPIRALS (Space Interoperable Refilling and Advanced Logistics Simulator), IPHITOS (Interoperable simulation of a Protection solution

based on light Interceptor Tackler operating in Outer Space) and SISMA (Medical Simulator of Astronaut including treatments, analysis and sickness models) (Bruzzone et al. 2016).

The simulator proposed in this case is designed to adopt the HLA IEEE1516 (High Level Architecture) standards and guarantees interoperability; the Federates could be based on stochastic models adopting combined simulation (continuous and discrete events combined together). The VV&A (Verification, Validation and Accreditation) for this simulation will be conducted along the entire FEDEP (Federation Development Process) by using SME (Subject Matter Experts) from Simulation Team and GAUSSTEAM (Quero et al. 2015).

9.5 Description of the different models

In this paragraph all the models are described. It is important to outline that for the purpose of this simulator the biological specimen encapsulated in the Nano-satellite are considered as a “black box” representing a reference for the on-board systems in terms of temperature to be maintained and data to be collected.

The simulation models include:

- Satellite Dynamics Model: the model regulates the physics of the satellite including motion and acceleration based on all its characteristics.
- Vector Dynamics Model: a specific model for the vector is included to reproduce the release process.

- Mechanical Model: Mechanical Systems devoted to release the CubeSat from the vector, the umbilical connections for power support during launch and interactions with movable parts.
- Observation Systems Model: this module simulates the sensors that are interacting directly with the black box constituting the biological specimen as well as the links of the sensors to the CubeSat Core Systems devoted to conduct measurements during the experiments on the specimen. This model should include failures and performance estimations related to the experimentation on the cells based on the data collection, boundary conditions, status of components and sensors.
- Thermal and Heat Exchange Model: the model of this system considers the thermal effects and heat exchange in the CubeSat with special attention to the cells for the experimentation. The aim of this module is to control the temperature of the cells at a constant value of 37°C balancing the radiated heat from and to the CubeSat.
- Ionizing and Radiations model: this model is devoted to evaluate performances of the sensors respect the "solar weather" and the estimated exposure to the radiation of the specimen. In addition, these models could reproduce the effect of radiations in terms of noise over the signals.
- Microgravity Environment model: it is the model of the sensors adopted to measure microgravity acceleration.
- Power Systems model (PS): the model deals with the computation of power absorbed and consumed/provided by the battery. This model considers the power request to

keep the temperature of the cell constant as well as consumptions due to sensor operations and communications. The model considers then dynamic charge-discharge curve of the lithium battery inside the cell depending from solar power received from the solar panels and the power required from the conditioning system; this model coupled with the satellite dynamic model allows to estimate the exposure of the solar panels to the sunshine and their efficiency in the different asset configuration respect Sun and Earth relative positions.

- Telemetry, Tracking and Communications System (TT&CS) model: this model reproduces the datalink that is a crucial component for ensuring correct operational profile. The cyber space is modelled in order to analyse the performances of the communication systems: the model allow to visualize the information packet flow and to evaluate communication system performances changing several parameters characterizing the communication nodes and links in terms of availability, reliability and confidentiality. The characteristics of the TT&CS are coupled with the dynamic evolution of the CubeSat around the Earth and respect the Ground Base devoted to receive the experimental data to identify when it is possible to communicate and how; in similar way the coupling with the Power System Model allows to consider the relative power consumption.
- On Board Computer model: it is crucial to implement and test the on-board computer system in a simulated environment before executing the mission. Simulation enables also the possibility to evaluate the performance of Artificial Intelligence module (AI)

devoted to direct dynamically the operation based on the level of decisional autonomy of the system during mission stochastic events such as failures or power shortage.

- Attitude and Orbit Determination and Control System model (AODCS): it simulates the performances of the sensors and modules devoted to control the orbit during the dynamic evolution of the mission. This module could be used by reverse engineering to define the requirements of this system to achieve a specific overall performance.
- On Board Software for Power Systems model (OBSW): that component simulate the control firmware addicted to the control system for the Power System Module.

Table 3 Description of the simulation parameters

Solar Exposition
Earth Sun distance [m]
Earth diameter [m]
Exposure Average angle [rad]
Starting Shadow Angle [rad]
Ending Shadow Angle [rad]
Power coefficient [W/cm^2]
Solar Panel Surface [cm^2]
number of panels
Potential Solar Power [W]
Current Efficiency of Solar Panels

Current Battery Charging [mAh]
Dynamic Model
Ground Station lat., long. & altitude
CubeSat latitude, longitude & altitude
CubeSat Asset: Pitch, Yaw. Roll[rad]
CubeSat linear and angular speeds
CubeSat Status of Operations
Vector latitude, longitude & altitude
Vector Asset: Pitch, Yaw. Roll[rad]
Vector linear and angular speeds
Thermal Model and Heat Exchange
Solar Constant [W m^-2]
Stefan's coefficient [W m^-2 K^-4]
T Sunshine Side of the CubeSat [K]
T Shadow Side of the CubeSat [K]
Emissivity Factor
Radiation Factor
CubeSat Surface [m_2]
Heat to be dispersed [W]
Insulation factor

Absorbed Energy on Exposed Face [Wh]
Dispersed Energy on shadow faces [Wh]
Current Energy Balance [Wh]
Battery Use for Heat Exchange [mAh]
SATCOM
max distance [m]
max power consumption [W]
Gain transmitter [dBi]
Gain receiver [dBi]
frequency [Hz]
N Exponent for Env. Conditions
Power receiver [W]
Communication Status
Bandwidth [Mb/s]
Efficiency Level
Data to be Transmitted [Mb]
Transmission Time [s]
Power Consumption [W]
Energy Consumption [Wh]
Battery Use for SATCOM [mAh]

Observation System Model
Dbase Capacity [Mb]
Data to be Transmitted [Mb]
Current Data flow [Mb/s]
Observation System Status
Battery
Nominal Capacity [mAh]
Operational Voltage [V]
Nominal Battery Energy [Wh]
Initial State of Charge
Current Capacity Level [mAh]
Current State of Charge
On Board Computer Model
Availability of the different systems
Current Battery use [mAh]

The Simulator models reproduce the dynamics of the CubeSat in terms of orbit, power generation and consumption, battery re-charging and communication management. In addition, the model considers the heating exchange and temperature control of the nanosatellite from the launching moment. Major model parameters are summarized in Table 3 Description of the simulation parameters.

The purpose of proposed simulation is to evaluate the performance of the system with special attention to the power required to keep the internal satellite temperature constant at 37°C and to communicate with the ground station. The total power required from the satellite is obtained by the interaction of models representing the different systems (e.g. AODCS, OBC, TT&CS and PS).

The energy to the different CubeSat systems is provided by the battery and by the solar panels that are used to recharge it.

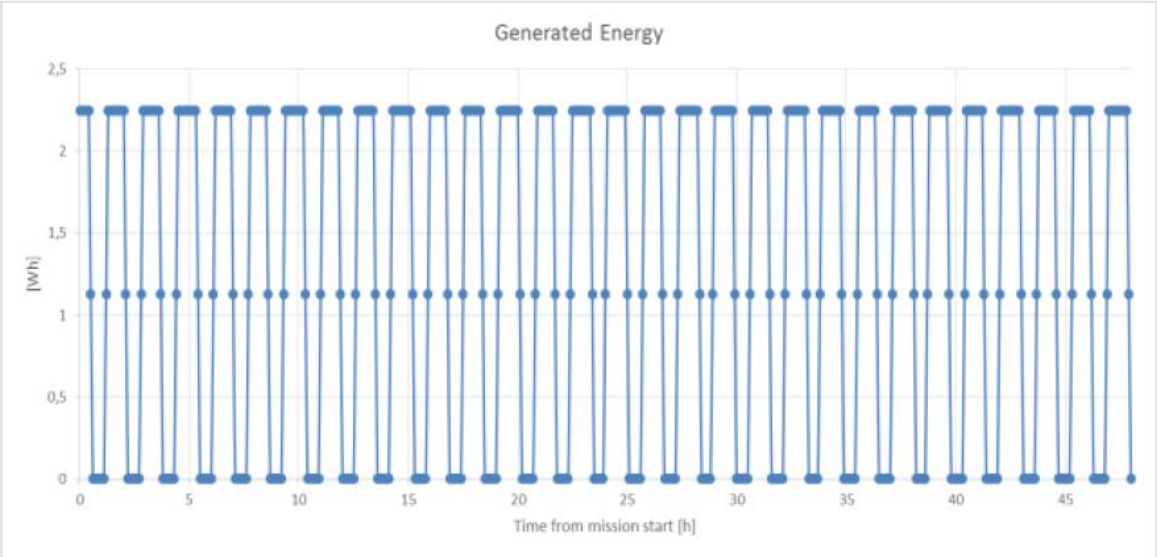


Figure 73 Generated Energy by Solar Panels

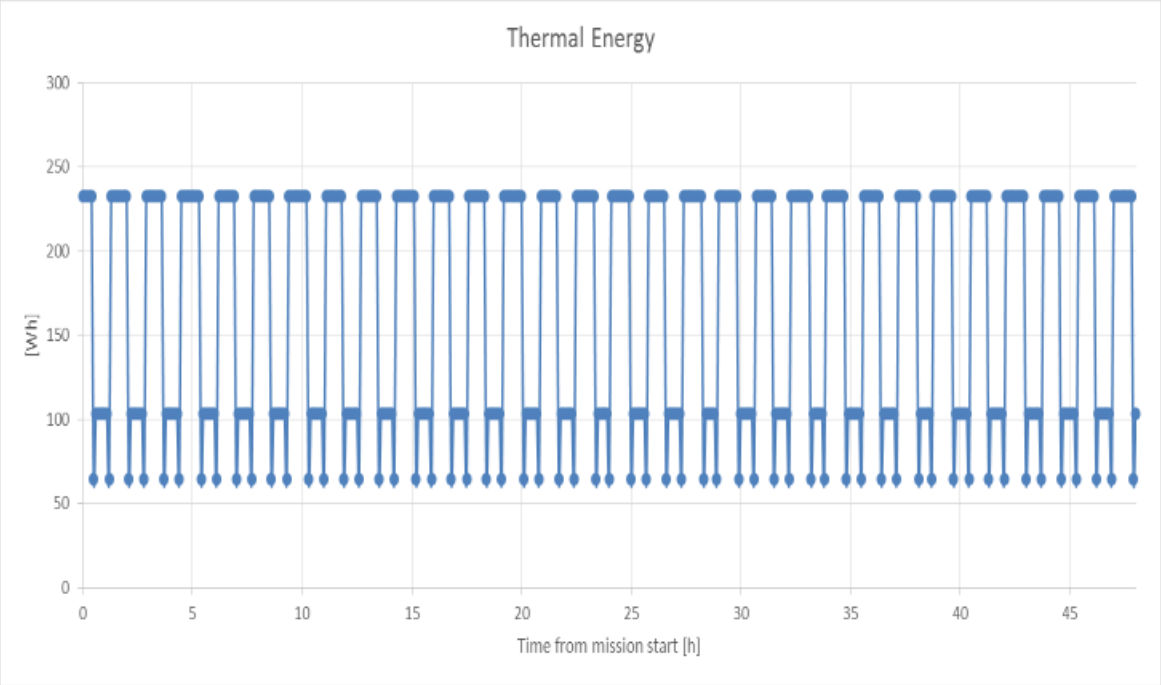


Figure 74 Thermal Energy Balance

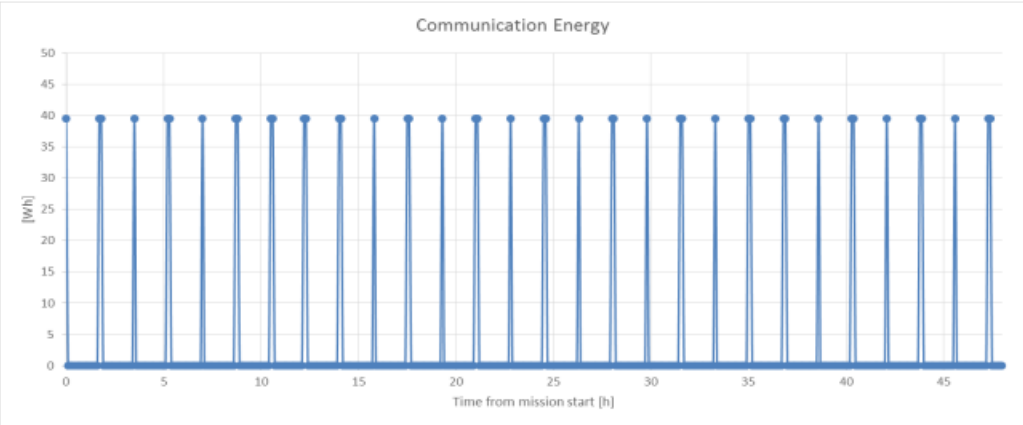


Figure 75 Energy required for Communications

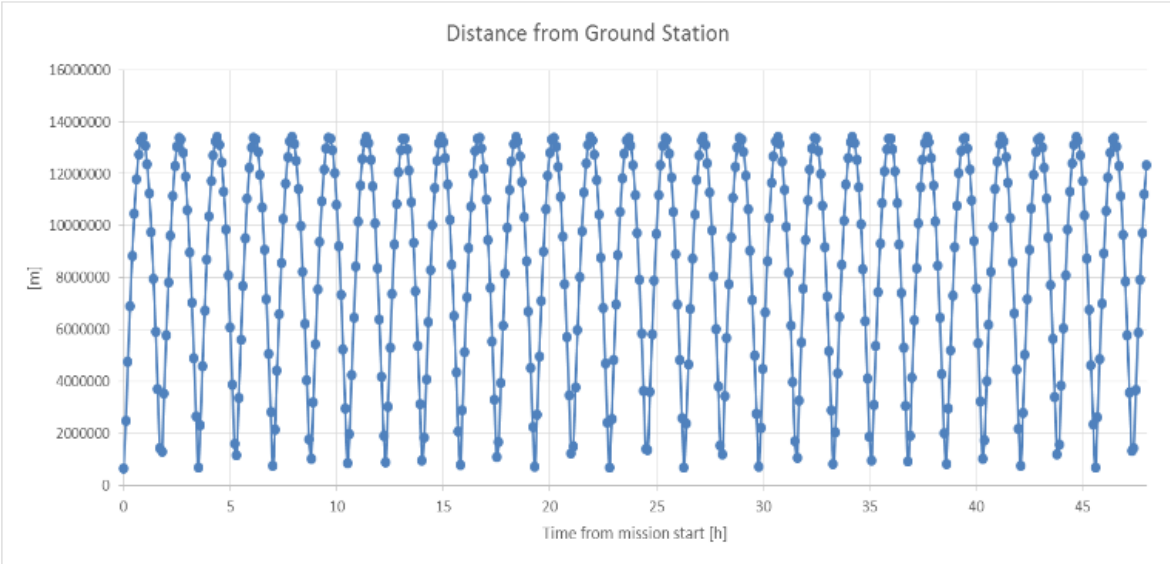


Figure 76 Communication Opportunities: CubeSat–Ground Base

The CubeSat is released by its vector when it is reached the proper operational orbit altitude; this process is activated by a simple spring mechanical device that releases it at a relative speed of 2.4 m/s perpendicular to the vector trajectory.

Obviously, the model computes the CubeSat orbit respect the movements of Earth and Sun, in order to evaluate dynamically the solar exposure and the conditions of low efficiency when the solar panels are affected by atmosphere (CubeSat relative sunset and sunrise); this allows to estimate the power generated by the solar panels in different conditions. In general, there are different situations including darkness, (no charge), shadow (partial charge) and full exposure (full charge).

Under the hypothesis of omnidirectional antenna, the cyber layer is modelled to analyse the conditions when communications are possible as well as the exchange of information with the ground station considering the relative orbital position of the satellite.

Indeed, the TT&CS model simulate all the data exchanges with the ground base, considering the different delay and the noise of the signal due to the position of the satellite. Since the CubeSat have a different rotation speed compared to the Earth, there are conditions where the satellite could not be able to transfer the data.

In these cases, the TT&CS close the communication with the Ground Base in order to save power and the OBC stores the experimental data in its dBase for late transmission opportunities.

9.6 Outcomes

In the section is described a simulation model of the systems devoted to conduct an experiment on tumour cells under micro-gravity and radiation conditions on a nanosatellite in space.

The conceptual model has been developed and implemented in order to support design, engineering, virtual prototyping and risk analysis about the different systems.

The simulation resulted very useful to create a virtual prototype to deal with the complexity of the different systems and their interactions as well as with the large number of the variables; in addition, the stochasticity related to the potential failures affects the mission success and requires proper risk analysis to identify most convenient satellite configurations and redundancies to mitigate problems.

By this approach it is possible to reduce risks and guarantee success in this context dealing with nanosatellite, so a pretty compact system of systems that needs to operate in space

guaranteeing success despite limited budget. Indeed, the use of simulation allows to improve design and reduce overall costs and risk; obviously it is fundamental to proper model the different systems and their interactions to proper reproduce the different operations and conditions even considering potential failures and interferences.

10 Conclusions

This work reports on the researches performed by the author on interoperability for modelling and simulation in maritime extended framework during the Ph.D. timeframe at the Genova University Polytechnic School at the Department of Mechanical, Energy, Management and Transportation Engineering within the Simulation Team.

The researches address M&S in all the environments of the Extended Maritime Framework, namely Sea Surface, Underwater, Air, Coast & Land, Space and Cyber Space, with all the developments performed according to international standards, in particular HLA interoperability standard IEEE 1516-2010, VV&A IEEE 1516.3 and DSEEP IEEE 1730.

In general, the outcomes of these Ph.D. researches show the great potential of M&S applications for the maritime extended framework, applied both to innovative unmanned vehicles and to conventional assets and human personnel.

Main objective of the study carried out during the Ph.D. has been the use of constructive simulation as a testbed for verification and validation of decision support systems in a variety of applications.

As an example, one of the specific system under analysis is an allocator of naval asset deployed for anti-piracy missions. In order to evaluate the performances of the asset allocator, the interoperable simulation has been set up to charge and animate the scenario assigning patrolling path to the assets deployed and outputs measures of performance. The

simulation showed the potential to provide useful feedbacks even with limited public data available. As side benefit of the research, M&S confirmed to be a safe and low cost environment for experimenting with innovative tactics in complex scenarios.

In the same framework of asymmetric threats, another study has been carried out to evaluate to which extent the adoption of augmented reality techniques can support operations with unmanned vehicles. This has been applied to an off-shore oil rig installation representing a critical infrastructure protection case. The simulation aimed at evaluating the impact of augmented information available to pilots of unmanned vehicles, tasked to inspect the behaviours of suspect assets in the vicinity of an off-shore platform. The stochastic simulation capability is in charge to reproduce suspect assets behaviours and the experimental campaign, performed with the involvement of a set of untrained pilots, shows promising results in terms of effectiveness of augmented reality techniques.

Within the same Augmented and Virtual Reality research topic, an industrial application has been investigated to understand how those techniques may support the services of distributed assets, specifically complex medical machineries installed in patients' homes. Augmented and Virtual Reality applications were devoted to support local operators and the remote supervisions of assets status. This approach proved, again, to be valuable especially for training staff operating the systems and reduce the costs due to involuntary damages to healthcare apparatus.

Coming back to the maritime domain, a discrete event stochastic simulation tool, named Model of Advanced pLanner for Interoperable Computer Interactive simulation

(MALICIA), has been developed to support decision making processes for interdiction operations.

This tool, applied to asymmetric threats studies for the Italian Navy, provided positive results and nurtured the great interests of the Navy to M&S to gain knowledge on unconventional scenarios.

Navies, in fact, have been traditionally involved in symmetric warfare operations, i.e. ship against ship, but nowadays the challenges posed by piracy and illegal immigration have to be addressed and require innovative out of the box strategies which needs to be investigated. Those innovative strategies strongly rely on the use of autonomous vehicle to increase persistence with maximum efficiency and reduce operations costs and risks and their consistent application has to be deeply investigated.

The stochastic discrete event federation of simulators developed, MALICIA, includes multiple manned and autonomous vehicles, the models cover the effects of environmental conditions including sea state, wind, fog, rain. Assets of blue team (friendly forces), grey team (civilian), and red team (threats), have been modelled developing Intelligent Agents Computer Generated Forces, reproducing their behaviours and their interactions. The simulation has been thoroughly subject to an experimental campaign for verification and validation purposes, which demonstrated its reliability in such a complex framework.

Within the framework of MALICIA, the adoption of Neural Networks has been investigated for two cases of anomaly detections. In this case MALICIA simulator has been applied on an illegal immigration scenario, thanks to its versatile architecture. The simulation has been

used to reproduce illegal immigrants and commercial vessels behaviours with models realized using public unclassified data, which slightly limited the capability of the simulation. The purpose of the study was to understand, from commercial vessels behaviours in the Mediterranean waters between Sicily and northern Africa, the possible presence of illegal immigrants or vessels in distress.

Two different neural networks have been developed for this purpose. The results obtained, even if limited by the amount of public data available, confirmed the potential of such approach and the interest of the navy on Artificial Intelligence applications.

Human behaviour modelling has been another topic faced during the Ph.D., mainly to address the reactions of populations during crisis situations. One of the simulations has been developed in the framework of the international cooperation between industries, agencies and academia within a NATO Modelling and Simulation Group; in this case the models have been devoted to simulate population reaction to extensive flooding and integrated in an HLA federation of simulators as well as real systems to create a common operational picture between civil and military authorities.

The last study on human behaviour modelling described in the thesis is set back in the extended maritime framework. It is in fact applied to coastal areas and it has been developed to address strategic decision-making process on multi coalition operations. The federation of simulators developed for SIMCJOH project has been verified and validated and demonstrated its potential as a tool for training operatives on the understanding of reactions of the population related to the decisions take by a commander within a UN mandate.

Last, but not least, in the thesis it is reported a case study for the space domain. The simulation has been developed to serve as virtual prototype for de-risking the design of microsatellites. The microsatellites in the case study were intended to be deployed to study the behaviours of tumour cells in microgravity environments. All the components on board microsatellites have been modelled, as well as their interactions. The results showed the potential of using simulation to mitigate the risks of a new design of sensible space assets.

To conclude, a variety of techniques and methodology have been fruitfully applied in the researches, ranging from interoperable simulation, discrete event simulation, stochastic simulation, artificial intelligence, decision support system and even human behaviour modelling. All the studies reported demonstrated the potential use and the impact of simulation as a safe environment, as well as the interest in both industrial and military communities on M&S applications.

The author of the thesis is currently enrolled in the NATO STO CMRE, where he is continuing to explore M&S applied on real life situations, in particular for applications on autonomous vehicles in the maritime domain.

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Annex A: Example of the Malicia ANN Configuration

In the following the example of the Matlab Function for the final immigration network

```
function [Y,Xf,Af] = net_30_20FCN(X,~,~)
%NET_30_20FCN neural network simulation function.
%
% Generated by Neural Network Toolbox function genFunction, 13-
Apr-2017 02:11:44.
%
% [Y] = net_30_20FCN(X,~,~) takes these arguments:
%
%   X = 1xTS cell, 1 inputs over TS timesteps
%   Each X{1,ts} = 42xQ matrix, input #1 at timestep ts.
%
% and returns:
%   Y = 1xTS cell of 1 outputs over TS timesteps.
%   Each Y{1,ts} = 2xQ matrix, output #1 at timestep ts.
%
% where Q is number of samples (or series) and TS is the number
of timesteps.

%#ok<*RPMT0>

% ===== NEURAL NETWORK CONSTANTS =====
```

```
% Input 1
x1_step1_xoffset =
[0;0;5.696698;14.012006;5.696698;14.012006;5.696698;14.012006;5.
696698;14.012006;5.696698;14.012006;5.696698;14.012006;5.696698;
14.012006;5.696698;14.012006;5.696698;14.012006;5.696698;14.0120
06;5.696698;14.012006;5.696698;14.012006;5.696698;14.012006;5.69
6698;14.012006;5.696698;14.012006;5.696698;14.012006;5.696698;14
.012006;5.696698;14.012006;5.696698;14.012006;5.696698;14.012006
];
x1_step1_gain =
[0.727687853347029;2;0.15965682722928;0.000951122077092121;0.159
65682722928;0.000951122077092121;0.15965682722928;0.000951122077
092121;0.15965682722928;0.000951122077092121;0.15965682722928;0.
000951122077092121;0.15965682722928;0.000951122077092121;0.15965
682722928;0.000951122077092121;0.15965682722928;0.00095112207709
2121;0.15965682722928;0.000951122077092121;0.15965682722928;0.00
0951122077092121;0.15965682722928;0.000951122077092121;0.1596568
2722928;0.000951122077092121;0.15965682722928;0.0009511220770921
21;0.15965682722928;0.000951122077092121;0.15965682722928;0.0009
51122077092121;0.15965682722928;0.000951122077092121;0.159656827
22928;0.000951122077092121;0.15965682722928;0.000951122077092121
;0.15965682722928;0.000951122077092121;0.15965682722928;0.000951
122077092121];
x1_step1_ymin = -1;
```

```
% Layer 1
b1 = [-1.3009688693697077;-1.5669067559344645;-
1.1239081566952354;-1.1314796094037571;-0.90755351972378839;-
0.79913890130915655;-0.71410120967793989;-
0.86390411226553887;0.78599113212450999;-0.40739649365887942;-
0.28937478939594707;-0.53403447051653419;-0.18968157637848232;-
0.023997464470860437;0.066273924904334106;0.22032388661030605;-
0.0088266878726439811;0.32405408248113593;0.42191671656139529;0.
71705229115206059;0.31614047818639851;0.65643988617696691;-
0.6666918863711826;0.73593179413761223;-
1.3042791358225636;0.99988290008701408;1.1428281140388539;1.3786
801555866346;1.2913705634097363;1.3424369657557824];
IW1_1 = [-0.20862251177288568 0.37759205148933261 -
0.21208350335073989 -0.40722565031834779 -0.17523770858413507 -
0.21881376467066946 0.17456655362751591 0.18395051018722899 -
0.22000440404723229 -0.34312218803172528 0.37544159418626444 -
0.36502933252510739 0.25390388447188011 0.084493057456990081 -
0.14419318097672498 0.60711328294736511 -0.016472722168389804 -
0.19424434380017488 0.044516425390685399 -0.069762032119796258
0.046214988646567846 0.22287773073756015 0.046287740696213782
0.20164545879766832 0.0099114774346026648 -0.32251580549263908
0.38150415568731627 0.13805502688267787 0.15859367098385699 -
0.00017847694302633663 -0.20098374307870756 -0.31021847428532717
0.06569417602446212 0.13196946546377208 0.19794683386265174
```

0.15597711553813051 0.063608889449918507 0.10014924912402108
0.21960612581688305 0.1820436364221826 -0.16156633722419472 -
0.4060743178111984;-0.69060704260871209 0.43536165098321861
0.010277913149140921 -1.9676347729750208 -0.094877214939567162 -
1.7082086251006967 0.063620759229834262 -0.25568474634899557
0.24683290340394201 -0.40196312039416049 -0.24707498076629106
0.31927858458288139 0.2180275681837299 0.72039243316310264 -
0.083672594508522019 0.64011993490285324 0.10059844591616937 -
0.07504974981075381 -0.036889900628639019 0.15523056905806673
0.0096641804133588589 0.17919932187385465 0.13613065010077943
0.48899179017588534 -0.21872711878525145 0.26585376571203201
0.061104336751549589 0.020886092836342428 0.018204649737396543
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0.021372144457904411;0.30871257971987298 0.19608785069166354
0.19316084129229039 0.29718857368663992 -0.30282812160932621
0.32028958691927911 -0.091166160413292133 0.15245034540791794 -
0.15653688024800927 -0.03960717457556253 -0.17757629510681919 -
0.10537485508316806 -0.26328675172919991 0.19410780059198848 -
0.28364636467632143 0.28259173590742948 0.12933009496212927
0.11814836576206314 0.28320459500720846 0.30651246997671777
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0.24341612216764197 0.19674913177589878 -0.15170500246942625 -
0.22193774652485929 -0.13497160426962368 -0.1345685992440637 -
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0.26139625586639892 0.10746043628923145 -0.0078304783389518701
0.222294873457411 -0.35984477114829977 0.47756580925780084
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0.29982770414452248 -0.005414232214820504 0.078184133409446341
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0.15405496865658691 -0.04143180644056909 0.030200977019744057 -
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0.14958047675669753 0.12805609709435464 -0.31814416441581672
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0.5849870864300678 -0.95937883890516706 0.059888992105943825 -
1.1596411539440887 0.86460384498641762 -0.9330418853489687
1.2739799671368661 0.3310405228552496 -2.038067997991742
1.4529476289937058 -0.43276585797139216 0.23561774674090208 -
0.44916913331257419 -0.66947578082716075 -1.1084042488495909];

% Output 1
y1_step2_ymin = -1;
y1_step2_gain = 2;
y1_step2_xoffset = 0;
y1_step1_xrows = 2;
y1_step1_remove = 2;
y1_step1_value = 0;
y1_step1_keep = 1;

% ===== SIMULATION ========

% Format Input Arguments
isCellX = iscell(X);
if ~isCellX, X = {X}; end;

% Dimensions
TS = size(X,2); % timesteps
```

```
if ~isempty(X)
    Q = size(X{1},2); % samples/series
else
    Q = 0;
end

% Allocate Outputs
Y = cell(1,TS);

% Time loop
for ts=1:TS

    % Input 1
    Xp1 =
mapminmax_apply(X{1,ts},x1_step1_gain,x1_step1_xoffset,x1_step1_
ymin);

    % Layer 1
    a1 = tansig_apply(repmat(b1,1,Q) + IW1_1*Xp1);

    % Layer 2
    a2 = tansig_apply(repmat(b2,1,Q) + LW2_1*a1);

    % Layer 3
    a3 = repmat(b3,1,Q) + LW3_2*a2;
```

```
    % Output 1
    temp =
mapminmax_reverse(a3,y1_step2_gain,y1_step2_xoffset,y1_step2_ymi
n);
    Y{1,ts} =
removeconstantrows_reverse(temp,y1_step1_keep,y1_step1_remove,y1
_step1_value,y1_step1_xrows);
end

% Final Delay States
Xf = cell(1,0);
Af = cell(3,0);

% Format Output Arguments
if ~isCellX, Y = cell2mat(Y); end
end

% ===== MODULE FUNCTIONS ========

% Map Minimum and Maximum Input Processing Function
function y =
mapminmax_apply(x,settings_gain,settings_xoffset,settings_ymin)
y = bsxfun(@minus,x,settings_xoffset);
y = bsxfun(@times,y,settings_gain);
```

```
y = bsxfun(@plus,y,settings_ymin);
end

% Sigmoid Symmetric Transfer Function
function a = tansig_apply(n)
a = 2 ./ (1 + exp(-2*n)) - 1;
end

% Map Minimum and Maximum Output Reverse-Processing Function
function x =
mapminmax_reverse(y,settings_gain,settings_xoffset,settings_ymin
)
x = bsxfun(@minus,y,settings_ymin);
x = bsxfun(@rdivide,x,settings_gain);
x = bsxfun(@plus,x,settings_xoffset);
end

% Remove Constants Output Reverse-Processing Function
function x =
removeconstantrows_reverse(y,settings_keep,settings_remove,setti
ngs_value,settings_xrows)
Q = size(y,2);
x = zeros(settings_xrows,Q);
x(settings_remove,:) = settings_value(:,ones(1,Q));
x(settings_keep,:) = y;
```

```
end
```

11 Annex B: Malicia Tests and DataModel

Test MALICIA

Several tests have been performed for the integration between the MALICIA simulator and the Navy Tactical Table. In this Section it is provided a summary of them.

1.1. Test MARITELE 19.04.2016 – 20/04/2016

The Tests were performed at MARITELE, in La Storta (Rome) with the aim to verify the correct connection between the MALICIA Simulator and the Tactical Table.

The test highlighted issues due to MALICIA Server (Leonardo) and MALICIA Client (Simulation Team) data transmission.

The issues have been identified and resolved giving the possibility to conduct further test on data exchanging.

The main problems addressed were:

- Misinterpretation by the MALICIA Server of some output data sent by the Client

- Slight instability in the allocation of different patrolling asset
- Lack of default values for some of the input variables.

1.2. Remote Test trough VPN 05/2016 - 12/2016

A VPN connection has been established to carry out intense remote testing campaign.

This allowed to conduct several tests in the months within May and December 2016.

The results achieved in this time frame are:

- A set of default values have been developed as backup in case input variable are not available (as highlighted in the paragraph above)
- A consistent number of MALICIA Server misinterpretation has been resolved
- The necessity to simulate a scenario in whatever part of the world (no more only in the Gulf of Aden) has been agreed, starting the implementation process of this feature

The remote test campaign highlighted the following issues:

- Misinterpretation of the patrolling routes of the assets

- Slight instability in the communication of the assets the coverage areas

1.3. Test MARITELE 18.01.2017 – 20/01/2017

The Tests were performed at MARITELE, in La Storta (Rome) aiming to verify that the problems identified in the remote test campaign were correctly addressed and resolved and further investigate possible rising issues in communication and data exchange.

In the test several actions were been performed, leading to:

- The discovery of the cause of assets patrolling routes misinterpretation
- The correct set up of the geographic zone requested by the Tactical Table in the simulator
- The correct interpretation of Threat and False Alarm probability
- The agreement to implement in the simulator the capability to discriminate if certain geographical area on the map are land or sea

The problem persisting after testing were:

- The assets coverage area missed some part of routes
- Patrolling routes misinterpretation problem

- Missing of some routine for discovering the part on the map that corresponding to land
- Problem on automatic start of the simulation

1.4. Remote Test trough VPN 01/2017 – 02/2017

The tests were performed trough VPN and they were conducted in order to address some of the issues identified in the previous test. The Action Performed were:

- Resolutions of the assets patrolling routes misinterpretation
- Discovering of the causes of the coverage area problem
- Resolutions of some asset input data misinterpretation
- Resolution of the automatic start problem

The problem persisting after the test were:

- The coverage area missed some part of routes of the assets
- Missing of a routine for discovering the part on the map that corresponding to land

1.5. Test MARITELE 02/02/2017 – 03/02/2017

The Tests were performed at MARITELE, in La Storta (Rome) aiming to verify that the problems identified in the remote test campaign were

correctly addressed and resolved and further investigate possible rising issues in communication and data exchange.

In the test several actions were been performed, leading to the following conclusions:

- The simulator took too long to run a simulation
- If the simulation name had an empty space, the simulator does not run
- If the entity list included more than 10 ships the simulator runs but gives no response back
- Routine to delete the previous input data was missing
- Missing of a routine for discovering the part on the map that corresponding to land
- The assets coverage area missed some part of routes

1.6. Remote Test trough VPN 01/2017 – 02/2017

The tests were performed trough VPN and they were conducted in order to address some of the issues identified in the previous test. The Action Performed were:

- Optimization of the run time to carry out a simulation

- Resolution of the area coverage problem
- Resolution of maximum number of assets problem
- Resolution of the simulation name problem
- Implementation of a routine to delete old input data
- implementation of the capability to set multiple runs of the same scenario
- implementation of the "action range" for each operating unit management

The issues persisting after the test were:

- Missing a routine for discovering the part on the map that corresponding to land

README

Malicia 1.1

Model of Advanced pLanner for Interoperable Computer Interactive simulAtion

Malicia Files:

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Input General Malicia Simulation file

Location

Directory ./scenario/

Example: ./scenario/

Simulation Settings malicia_sim.mal

Example: ./scenario/malicia_sim.mal

* simulationname scenarioname date duration replications asset_samp_int area_samp_int condition

*

simulationname name of the simulation experiment

scenarioname name of the scenario

date starting date of the simulation in terms of date expressed as YYYYmmDD

time starting time of the simulation in terms of date expressed as seconds

from 00:00:00 GMT;currently use zero [s]

duration duration of the period to be simulated expressed in terms of hours [s]

replications identificative replication number

asset_samp_int asset sampling interval expressed in delta time [s]

area_samp_int areas sampling interval expressed in delta time [s]

condition condition of action to be done expressed by following possible strings:

go! please execute simulation

going_[i] simulation is on going and currently the i-th replication is in execution

gone simulation completed

manual standby (default)

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Input General Malicia Scenario files

Location

Directory ./scenario/[namescenario]

Example: ./scenario/aden

All floating point numbers are expressed in decimal form using '.' as separator among

integer part and decimals.

In this directory it should be included the following two files width default values

for statistical conditions:

malicia_mat_general.mal

malicia_mat_matrix.mal

Assets malicia_assets.mal

Example: ./scenario/aden/malicia_assets.mal

Information used by the Simulator on the Assets will be obtained by asset file

(i.e. malicia_assets.mal).

One line for each asset (including Vessels, RHIB, UAV, MPA, etc) starting with asterix ('*')

and with asset variables divided by commas (',')

* id, name, description, type, subtype, motiontype, lat, long, height_deept, current_speed, current_course, max_speed, cruise_speed, max_speed_acc,

max_rotspeed, max_rotacc, range_radar_e, range_visua_e, range_action, autonomy, autonomymax, safety, flir,

prob_to_detect, prob_to_classify, prob_to_engage, time_to_detect, time_to_classify, time_to_engage, status, tempopreparazione, dcosts,

nuav, nrhib, nheli, father, mtbf, mttr, preventivem, basem, durationm, assigned_plan $

*

id progressive id [0..100]

name name of the asset without spaces (" ") and commas (",") please substitute with "_"

description description of the asset without spaces (" ") and commas (",") please substitute with "_"

type code (-1 void, 1 surface vessel friendly, 69 surface foe, 70 surface neutral, 101 Rotary wing friend,

102 uav friend, 103 rhib friend, 104 mpa, 201 VPD)

subtype subtype code (1 frigate, 2 destroyer, 3 cruiser, 4 submarine)

sop operative status

motiontype type of motion (0 surface, 1 flying, -1 submarine)

lat current latitude in degrees with decimal and sign (e.g. -4.17231)

long current longitude in degrees with decimal and sign (e.g. 32.272213)

height_deept current altitude or depth [m]

current_speed current speed [m/s]

current_course current course [degrees] (e.g. 173)

max_speed max speed [m/s]

cruise_speed cruise speed [m/s]

max_speed_acc max linear acceleration [m/s2]

max_rotspeed maximum rotational speed [degree/s]

max_rotacc maximum rotational acceleration [degree/s2]

range_radar_e max range of the radar versus SMB (Small Medium Boat) in optimal condition [m]

range_visua_e max range of the EO/IR versus SMB (Small Medium Boat) in optimal condition [m]

range_action max range to activate the action versus a suspect boat in [m]

autonomy current residual autonomy expressed in m respect cruise speed

autonomymax maximum autonomy expressed in m respect cruise speed

safety safety coefficient for autonomy and operation range [0.0 .. 3.0]

flir sensor capabilities in ir with all-weather/night [0.0 .. 1.0]

prob_to_detect probability to detect target successfully [0.0 .. 1.0]

prob_to_classify probability to classify target successfully [0.0 .. 1.0]

prob_to_engage probability to engage target successfully [0.0 .. 1.0]

time_to_detect average time requested to detect when in range [s]

time_to_classify average time requested to classify when in range [s]

time_to_engage average time requested to engage when in range [s]

status operational status [0.0 .. 1.00]

tempopreparazione time to be ready to change operational mode [s]

dcosts daily cost [kEuro/day]

nuav number of uav on board

nrhib number of rhib on board

nheli number of heli

father id of the reference asset when asset based (eg.helicopter based on frigate id 138

or -1 if the unit is not asset based, example a frigate)

mtbf mean time between failures [s]

mttr mean time to repair [s]

preventivem time of next preventive maintenance expressed in seconds from simulation start [s]

basem base for preventive maintenance

durationm maintenance duration [s]

assigned_plan id of the assigned patrol

$

Patrolling Plans malicia_plan.mal

Example: ./scenario/aden/malicia_plan.mal

Information used by the Simulator on the Patrol Plans will be obtained by plan file

(i.e. malicia_plan.mal).

One line for each point of the planning path starting with '*' and variables divided

by commas (',')

* x, y, lat, long, i, distance, duration

*

x id of the path plan

y id of the vessel assigned to x path plan

lat latitude decimal of the point i-th

long longitude decimal of the point i-th

i progressive number of the i-th point of the path plan

distance distance between i-th point and (i-1)-th point (currently not used and set to -1
for calculating the distance based on coordinates) [nM]

duration duration to spend in order to reach i-th point from (i-1)-th point (currently not used
and set at -1 for cruise speed) [h]

Time/Space Input over the Matrix about Boundary Conditions (e.g. Weather and

Probabilities) is located in

Location:

Directory ./scenario/[namescenario]/[datescenario]

[namescenario] String without spaces representing the scenario name (e.g. "aden")

[datescenario] Sub Directory named "date" (e.g. 20140812) with the starting date

of simulation in format yyyyMMdd

Example:

./scenario/aden/20140930/malicia_mat_0003_20140930_030000.mal

All floating point numbers are expressed in decimal form using '.' as separator among

integer part and decimals.

Malicia Zone General Info malicia_mat_general.mal

Example:

./scenario/aden/20140930/malicia_mat_general.mal

This file includes the information about the zone subjected to the patrol plan in terms

of size, resolution, timeframes.

The .mal file (ASCII with commas as separator ',') for General info: malicia_mat_general.mal

Data Format

* x1,x2,x3,x4,i1,i2,i3,s1,i4,i5, $

*

x1 Lower Bound of the Matrix area in Latitude decimal (-13.5 corresponding to 13 30 S)

x2 Lower Bound of the Matrix area in Longitude decimal (45.75 corresponding to 45 45 E)

x3 Hi Bound of the Matrix area in Latitude decimal (-13.5 corresponding to 13 30 S)

x4 Hi Bound of the Matrix area in Longitude decimal (45.75 corresponding to 45 45 E)

i1 Matrix number of segment along x (West to East) currently to be fixed at 20

i2 Matrix number of segment along y (South to North) currently to be fixed at 20

i3 Matrix number of segment along z (quote from sea level), currently not in use (i.e. set to 1)

s1 Initial Date of the Simulation expressed as yyyyMMdd (e.g. 20140812)

i4 Initial Simulation Time expressed in hours from midnight GMT (e.g. 0), currently use

zero

i5 Delta Time for Geo Temporal Matrix updates expressed in hours (e.g. 3), please

use 3 as default value

$ terminating character

Example

* -13, 40, 30, 80, 20, 20, 1,20140930,000000,3,$

Malicia Boundary Condition Matrix

The .mal file (ASCII with commas as separator ',') for Boundary Conditions on weather and

probabilities are stored in files such as

info: malicia_mat_0000_20140930_000000.ccs or malicia_mat_0003_20140930_030000.mal

Example:

./scenario/aden/20140930/malicia_mat_0003_20140930_030000.mal

Name Format:

malicia_mat_[n1]_[n2]_[n3].ccs

[n1] progressive hours since start of the simulation expressed with 4 digits adding

leading zeros (e.g. 0003, 0282)

[n2] date in format yyyyMMdd (e.g. 20140930) of the corresponding to matrix data

[n3] hour along the day corresponding to matrix data expressed with 6 digits adding

leading zeros for hours and 00 00 for minutes and seconds (e.g.060000)

In case, some variables are not currently available or managed you could decide to

setup to zero (e.g. v0=0 corresponds to no current) or to setup to -1, in this case

the value of last loaded data will be adopted for the Matrix along the next timeframe.

Data Format

*,

[0-0-0 v1],[0-0-0 v2],[0-0-0 v3],[0-0-0 v4],[0-0-0 v5],[0-0-0 v6],[0-0-0 v7],[0-0-0 v8],[0-0-0 v9],[0-0-0 v10],[0-0-0 v11],[0-0-0 v12],$

[0-1-0 v1],[0-1-0 v2],[0-1-0 v3],[0-1-0 v4],[0-1-0 v5],[0-1-0 v6],[0-1-0 v7],[0-1-0 v8],[0-1-0 v9],[0-1-0 v10],[0-1-0 v11],[0-1-0 v12],$

....

[19-19-0 v1],[19-19-0 v2],[19-19-0 v3],[19-19-0 v4],[19-19-0 v5],[19-19-0 v6],[19-19-0 v7],[19-19-0 v8],[19-19-0 v9],[19-19-0 v10],[19-19-0 v11],[19-19-0 v12],$

Generic element [j1-j2-j3 vx] (e.g. 0.87262)

j1 number of element along x axis of the matrix (0 to i1-1)

j2 number of element along y axis of the matrix (0 to i2-1)

j3 number of element along z axis of the matrix (0 to i3-1)

hx value of the x-th factor:

case 0: v0 current speed in m/s

case 1: v1 current direction in degrees

case 2: v2 wind speed in m/s

case 3: v3 wind direction in degrees

case 4: v4 sea force in Beaufort

case 5: v5 direction of waves in degrees

case 6: v6 fog visibility in m

case 7: v7 rain intensity [0-100]

case 8: v8 peak period of waves in seconds

case 9: v9 wave height in m

case 10: v10 probability to generate a pirate in this matrix geoelement along the delta time frame (3 hours)

case 11: v11 probability to generate a false alarm in this geomatrix

element along the delta time frame (3 hours)

$ terminating character

Example in file malicia_mat_0000_20140930_000000.mal

==========

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Simulation Output files

Location

Directory ./scenario/[namescenario]

Output: Asset Situation Report

malicia_assetstatus_r_[name]_[replication]_[scenario].txt

name simulation name

replication current replication

scenario name of the scenario

Example:

./scenario/malicia_status_r_alfa_3_aden.mal (3rd replication of alfa simulation on aden scenario)

Report on current situation of Assets and Tracks

* tk, sk, id, name, type, subtype, sop, lat, long, height_deept, speed, course, range, costs

*

tk time till now since simulation time expressed in seconds [s]

sk current time elapsed since simulation start

expressed as: [m] days [hours]:[minutes] example: 2 days 10:20

id id of the asset

name name of the asset

type type of asset

subtype subtype of asset

sop operative status

lat current latitude in degrees with decimal and sign (e.g. -4.17231)

long current longitude in degrees with decimal and sign (e.g. 32.272213)

height_deept current altitude or depth [m]

speed speed [m/s]

course course

range effective range [m]

costs total cost at current time for this asset

Output: Target Variables Report malicia_output_r_[name]_[replication]_[scenario].mal

name	simulation name
replication	current replication
scenario	name of the scenario

Example:

./scenario/malicia_output_r_alfa_3_aden.mal (3rd replication of alfa simulation on aden scenario)

ASCII File including temporal evolution of controlled variables separated by commas,

each line corresponding to a different timeframe

* tk, sk, succ_detection, succ_classification, succ_engagement, tot_pirates, tot_piratesd, tot_piratesc,

tot_piratese, tot_alarms, tot_alarmsd, tot_alarmsc, tot_alarmse, kkkv, area_curr, area_tota

*

tk time till now since simulation time expressed in seconds [s]

sk current time elapsed since simulation start expressed as: [m] days [hours]:[minutes] example: 2 days 10:20

succ_detection total of successfull detection

succ_classification total of classification detection

succ_engagement total of successfull engagement

tot_pirates total pirates in the area

tot_piratesd total detected pirates

tot_piratesc total classified pirates

tot_piratese total enaged pirates

tot_alarms total false alarms in the area

tot_alarmsd total detected false alarms

tot_alarmsc total classified false alarms

tot_alarmse total engaged false alarms

kkkv total costs till now [kEuro]

area_curr current area coverage with the plan till now [km2]

area_tota total area coverage with the plan till now [km2]

Example:

* 0 0 0:0 0 0 0 0 0 0 0 16 0 0 0 0 0 0

Output: Coverage Areas Report malicia_areas_r_[name]_[replication]_[scenario].mal

name simulation name

replication current replication

scenario name of the scenario

Example:

./scenario/malicia_areas_r_alfa_3_aden.mal (3rd replication of alfa simulation on aden scenario)

The data will include information about the zone to be investigated and the tiles explored corresponding to
explored areas.
So the investigated zone is a large rectangle expressed in terms of latitude and longitude as well as in
terms of resolution (matrix n x m), while the explored areas corresponds to the cells of the matrix as
rectangles within the zone of few miles each.
ASCII File including information of explored areas and area currently under control; area not explored
are not reported

The file have a header line for each new data collection (initiated by '*') followed for a line for each tile
(initiated by '$')

* sname, tk, sk, lat_start, long_start, lat_end, long_end, lat_amplitude, long_amplitude, n, m,

$ i1,j1, e1

$ i2,j2, e2

$ i3,j3, e3

$ in,jn, en

*

sname simulation name

tk time till now since simulation time expressed in seconds [s]

sk current time elapsed since simulation start

expressed as: [m] days [hours]:[minutes] example: 2 days 10:20

lat_start starting latitude in degrees with decimal and sign of the zone to be investigated (e.g. -13.0)

long_start starting longitude in degrees with decimal and sign of the zone to be investigated (e.g. 40.0)

lat_end ending latitude in degrees with decimal and sign of the zone to be investigated (e.g. 37.0)

long_end ending longitude in degrees with decimal and sign of the zone to be investigated (e.g. 80.0)

n resolution among the latitude corresponding to n elements (i.e. 1000)

m resolution among the longitude corresponding to m elements (i.e. 1000)

lat_amplitude latitude amplitude of the tile corresponding to effectively explored area [Nm]

long_amplitude longitude amplitude of the tile corresponding to effectivelyexplored area [Nm]

$

i1 information related to the i1-th element of the n x m matrix corresponding

to explored area i1-th along latitude

j1 information related to the j1-th element of the n x m matrix corresponding

to explored area j1-th along longitude

e1 status of i1-th j1-th explored area (i.e. x: explored since simulation start

higher value corresponds to most recent exploration,

255: currently under coverage, 0: to be covered currently not used)