MODEL OF AN ADVANCED PLANNER FOR INTEROPERABLE COMPUTER INTERACTIVE SIMULATION

Agostino G. Bruzzone[1], Marina Massei[1], Riccardo Dimatteo[2], Giovanni L. Maglione[2]

[1] **DIME University of Genoa**
Via all'Opera Pia 15, 16145 Genoa, Italy
Email: {agostino, massei}@itim.unige.it
URL: www.itim.unige.it

[2] **Simulation Team**
Via Molinero 1, 17100 Savona Italy
Email: {riccardo.dimatteo, maglione}@simulationteam.com
URL: www.simulationteam.com

ABSTRACT

This work proposes 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 within the framework of anti-piracy operations and can be easily converted to the illegal immigration context. The simulation involves different kind of assets such as surface vessels, underwater vehicles, MPA, UAVs, helicopters etc.

Keywords: *Modelling and Simulation, Joint Naval Training, Decision Support System*

INTRODUCTION

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

Performing these activities, the Navies involved need to operate effectively and efficiently through sustainable actions to reach durable results while facing limited resources. Furthermore, the available assets are designed for different purposes: deployment of such units imply a significant effort in term of cost and adaptability.

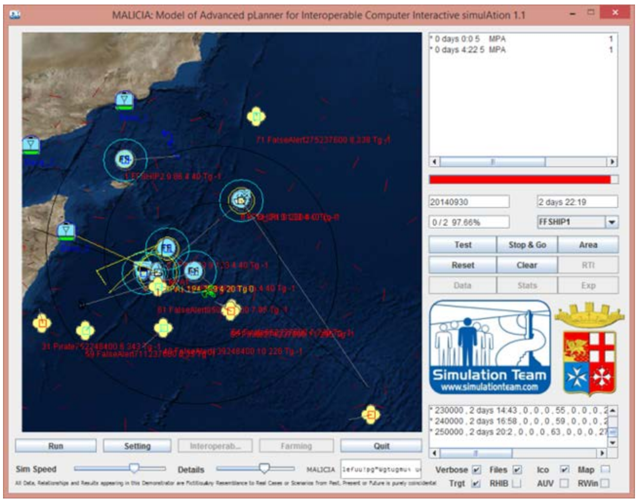
Another crucial element is the strong dynamism of the phenomena under analysis. In fact, the players tend to respond quickly to countermeasures while dynamically adapting their strategies, forcing the Navies to revise planning and procedures continuously.

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, such as use of autonomous systems and advanced data fusion techniques 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 require often support by Modeling & Simulation (M&S). In facts by this approach it becomes possible it to evaluate the overall performance in order to understand the specific procedures to be adopted for using them in the most effective and efficient way and to avoid/anticipate potential problems (Massei et al. 2011). All these issues are subjected to stochastic factors such as failures, false alarms, times, costs, etc.; so it is evident that the simulation is the cornerstone to support this context. In fact, the systematic use of the M&S (Modeling and Simulation) provides strategic support in decision-making process improving both the effectiveness, that the flexibility and robustness of the planning (Bruzzone et al. 2014b; Bruzzone et al. 2013e).

1. CURRENT SITUATION AND RESEACHES

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 a not a complete operative part of the missions. In facts the capability of autonomous assets could enhance mission success; therefore it is necessary to analyze how such innovative assets should be used so to finalize their selection or parameters design 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 very useful insight in advance (Longo et al., 2013, Longo et al. 2015) even when dealing with emerging behaviors and situations (Oren and Longo, 2008).


MALICIA: Model of Advanced pLanner for Interoperable Computer Interactive simulAtion 1.1

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Verbose ☑ Files ☑ Ico ☑ Map ☐
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All Data, Relationships and Results appearing in this Demonstrator are Fictitious. Any Resemblance to Real Cases or Scenarios from Past, Present or Future is purely coincidental

Figure 1 – MALICIA GUI

Simulation of maritime operations is thus an advanced and consolidated tool, using sophisticated models to reproduce the actual behavior of different types of vehicle involved in these scenarios. Among others, there have been developed specific models of MPA (Maritime Patrolling Aircraft) and UAVs to study the advantages and possible applications (Brennan & Denton, 2004, Pereira et al. 2009). Indeed, the scenario under analysis is very complex characterized by total heterogeneity of vehicles and strongly the environmental conditions 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 analyzed 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 small medium boats (e.g. RHIB) so it is evident the importance to model 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 kind of models were developed originally due to the increase on piracy that had a great on commercial maritime traffic, estimated between 1 and 16 billion US$ by UNCTAD (United Nations Conference on Trade And Development); this leads commanders and policymakers to task scientists to develop decision support tools generating patterns and behavior 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 even 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: in it there are 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 are able to recreate the behavior of pirates present in the simulation reproducing rational and emotional reactions to patrolling assets (Bruzzone et al. 2015b). 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 useful tool (Bruzzone et al. 2011a, Cavallaro et al. 2007). By this approach the simulator could result able to manage and use effectively unmatched input parameters and to address the uncertainty of the scenario. In addition, the simulation is rapid, 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.

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

2. CONCEPTUAL MODEL

The simulator proposed in this paper is called MALICIA (Model of Advanced pLanner for Interoperable Computer Interactive simulAtion). MALICIA model derived from a previous project called PANOPEA (Piracy Asymmetric Naval Operation Patterns modeling for Education & Analysis) and represent a stochastic discrete event simulator for maritime interdiction (Bruzzone et al. 2011d). In facts MALICIA is focusing on Maritime Interdiction Scenarios and could be applied to different cases from piracy to illegal immigration or anti-smuggling missions; The simulator simulates the maritime interdiction by modeling the general framework, platforms, C2 and even the specific anti-piracy operations or illegal immigration interdiction procedures. MALICIA reproduces weather conditions over wide area considering influence on sensor and platforms; the model cover fog, rain, wind, current, waves. In addition the simulator includes models of multiple assets such as MPA, Vessel, AUV, Helicopters, Submarines, Cargo, Yachts, Fishermen Boat, etc.; these entities are driven and operated by IA-CGF (Intelligent Agent Computer Generated Force) that reproduce their behavior and their interaction dynamics (Bruzzone et al. 2013c). In facts the assets simulated by intelligent agents interact dynamically each other in to recreate the dynamic simulation needed to those kind of scenarios (Bruzzone 2013a).

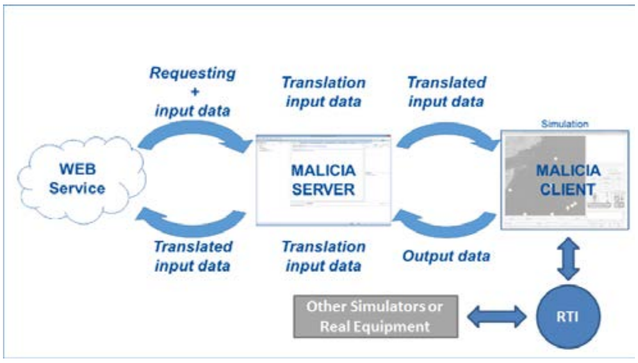

Figure 2 – MALICIA Architecture

The model receives the data input from web services and interacts with Tactical Naval Situation; the model includes commercial traffic, threats and false alarms. MALICIA evaluates the measures of merit as individual factors as well as overall performance covering Efficiency, Risk and Costs of the whole planning proposed by the user or generated by an intelligent decision support system (Bruzzone et al. 2006). For these reasons, MALICIA represents a useful instrument for supporting dynamic Operation Planning and Optimization. In facts the proposed approach support both the automated used in connection with optimizers as well as interactive use with decision makers refining interactively the planning based on the result of the simulator.

3. IMPLEMENTATION

MALICIA GUI (Graphic user interface) is proposed in figure 1, while the overall structure is presented in figure 2 and described in the following. The simulator is divided into two components: MALICIA Server and Client.

The Server is the component developed to establish the communications with the web services and MALICIA Client and it operates as Dbase server. The Server main tasks are receiving requests and data input from web applications especially related to the up-to-date situation of the vessels and the weather conditions; the server takes care of acquiring the input data in the correct way and to propose them to MALICIA Client and send back the results of the simulation to web services connecting MALICIA with the planning framework that uses touch screen technologies over wide board for supporting decision makers in their planning..

The Client is the real simulator elaborating input data simulating the scenario and providing the output to the Server; MALICIA is designed to be federated within an High Level Architecture interoperable federation with other models in case it should be used as part of a distributed simulation.

Indeed MALICIA is ready to be used both stand-alone and federated, as well as connected with Dbase by web services or operating on local data sets. In stand-alone mode the input data should be pre-compiled, instead when is connecting with web services the Requesting application should send the data input continuously to keep the simulator on-line with the real situation (Bruzzone et al. 2002a, 2002b).

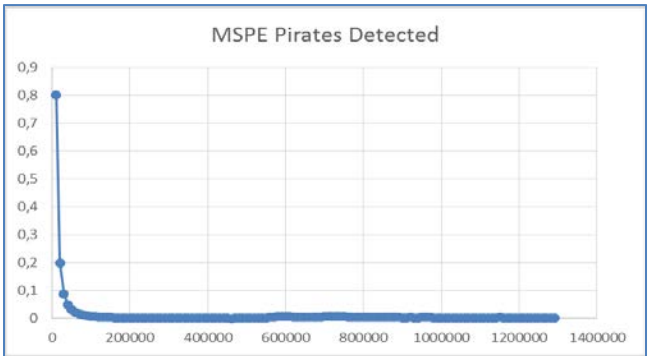

Figure 3 MSPE of Prates Detected Target Function

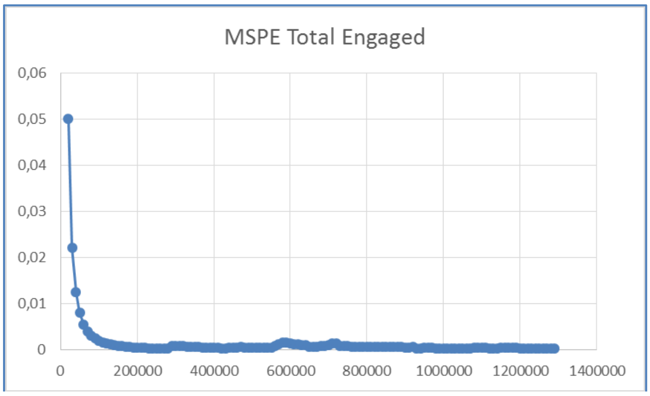

Figure 4 MSPE of Total Small Boat Engaged Target Function

Due to the quantity and the complex nature of input data it proposed a specific set of variables that could be also partially incomplete.

This particular solution has been adopted in order to run the simulation even in case of missing data. In this case users feeds the simulation with his available data and for the missing ones it is assume to use the standard value from a reference dbase developed and implemented by the authors based on historical data.

MALICIA Client receives as input from Dbase manager:

- Weather Conditions: actual and provided during the period of the simulation (given by a web services when is possible)
- The assets used in the simulation with a defined set of technical characteristics (e.g. name, speed, autonomy) and rules of engagement.
- Patrolling routes associated to the assets.
- A probability map of possible presence of pirate threats or illegal immigrants.
- General data about number of interactions, duration of the simulation, resolution of output data, the scenario size.

The model reproduces assets behavior during the period of simulation, taking into account their interactions and the influence of the boundary conditions. Simulation is able to run real time or fast time based on user preferences; in a complex scenario involved a dozen of assets with their resources (i.e. on board helicopters, UAV, RHIB) the simulator at fastest speed is able to cover 3 days of activity in few minutes.

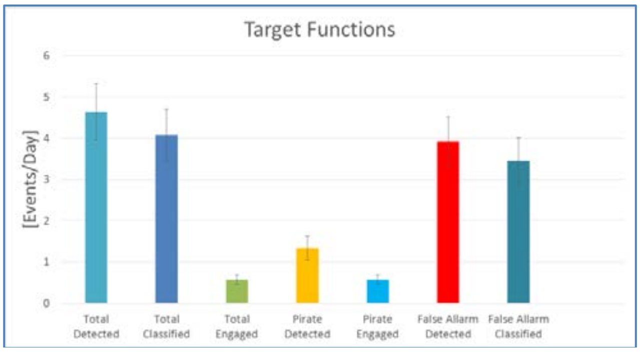

Figure 5 Events per Day for each Target Function

The simulator reproduces small-medium size boat representing commercial traffic and pirates. The assets employed in patrolling and block operations are capable to Detect (boat enters asset sensor range), Classify (distinguishes pirates from false alarms) and Engage (performs actions to intercept or neutralize menaces). Succeeding in the actions depends on onboard systems availability and reliability, influenced by the stochastic evolution of the simulation (e.g. drones not available because in maintenance, sensor failure) and by weather condition. The simulator provides detailed log about the operations such as:

- Patrolled area by the assets employed
- The tracking and operations of all the different assets and their technical-operational conditions
- A scenario general overview including the cumulative temporal distribution of the following target functions: number of false alarms, number of piracy threats, number of detections, classifications and engagements performed for each category (False Allarms, Pirates, Overall) during the time period simulated and differentiated for the different types (i.e. successfully classified, unsuccessfully classified)

4. EXPERIMENTATION

The experimental campaign is focusing on a specific set of the target functions covered by the simulator and specifically on the following ones:

- Total Small Boat Detected by the assets
- Total Small Boat Classified by the assets
- Total Small Boat Engaged by the assets
- Pirates Detected by the assets
- Pirates Boat Classified by the assets
- Pirates Engaged by the assets
- False Alarms Detected by the assets
- False Alarms Boat Classified by the assets
- False Alarms Engaged by the assets

Replicated simulations with the same initial boundary conditions, but different random seeds for the statistical distributions of the simulator have been performed. The Data have been collected every 10’000 simulated seconds for a total simulated time of 15 days (1’296’000 seconds).

In figure 3 and 4 it is proposed the analysis of the experimental error due to the pure influence of stochastic component for Pirates Detected and Total Small Boat Engaged Target Function (Balci 1998, Montgomery 2000, Kleijnen 2007, Telford 2012).

ANOVA technique have been applied and it was possible to verify and validate the target functions stabilization based on Mean Square pure Error Temporal Evolution analysis. So, Figure 5 shows the average number of events per day for each target function and the amplitude of the confidence band due to the stochastic nature of the simulation. Obviously the variance is pretty large, therefore the values and results result consistent with the fidelity requirements for being applied to maritime interdiction planning.

CONCLUSIONS

Maritime interdiction has evolved along last years and the recent immigration issues are emphasizing the importance to improve efficiency and effectiveness of these operations. MALICIA simulator, described in the paper, represents a good example of interoperable, strongly reliable Modelling and Simulation approach to support planning. The simulator has been validated through the experimental campaign and the results proposed demonstrate its potential.

The analysis are conducted on simulations confidence band, the results validate the simulator, showing a good convergence of the MSPE after the second simulated day. The positive results show the potential of these types of simulations applied to maritime interdiction and the possibility to integrate it with intelligent planning optimization tools. The simulator in this case would be elaborating and testing the proposed planning to support decision making process. Currently the authors are developing a tailored configuration to address sea border protection.

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