MODELING HUMAN BEHAVIORS IN MARINE ENVIRONMENT FOR ANTI-PIRACY OPERATIONS

Agostino G. Bruzzone, Marina Massei
DIME University of Genoa
agostino@itim.unige.it massei@itim.unige.it
URL: www.itim.unige.it

Irene Piccini
Life Sciences and Systems Biology
University of Torino
Email: irene.piccini@unito.it
URL: www.unito.it

Alberto Tremori
NATO STO CMRE
Email: alberto.tremori@cmre.nato.int
URL: www.cmre.nato.int

ABSTRACT

The paper addresses the need to create realistic simulation environments to test operational procedures and technological solutions for maritime interdiction with special attention to Piracy; the authors developed human behavior models to represent the maritime traffic and their rational and emotional reactions to the patrolling vessels and to their actions; this simulation applies intelligent agents and stochastic discrete event simulation for addressing this context and it was experimented also within an interoperable framework to be federated with real systems (e.g. C2, planners) and with other models (e.g. weather forecasts, training equipment).

Keywords: *Human Behavior Modeling, Intelligent Agents, Maritime Interdiction, Discrete Event Simulation*

1. INTRODUCTION

In complex scenarios involving presence of humans it is always pretty hard to develop simulations able to consider the influence of the people behavior; even in maritime sector the presence of general cargo, pleasure craft and small medium size boats is often very high affecting the whole scenario; this aspect becomes even more critical when it becomes necessary to address asymmetric threats that are hard to be discriminated within the traffic and that use it as a coverage operating as not cooperative targets and adopting special behaviors.

This becomes evident if we think to the problem to identify fishing vessels that are carrying out smuggling or illegal immigration actions over a scenario among others operating regularly; in this sector the use of technological solution, mature command and control and operational procedures is crucial, but to evaluate their efficiency and resilience respect false alarms it is pretty hard due to needs of time and costs for experiencing them at sea and the limitation of fixed scenarios. Indeed it is evident the necessity to use stochastic simulation to address these aspects respect other methodologies [3] even in order to identify emerging situation [44]. Therefore in case of trace driven scenario, regulated by historical data, the limited or absent interaction with the interdiction actions requires to be able to reproduce rational and emotional reaction and behavioral model should be introduced; it is evident that a smuggler is not escaping as soon as he perceive the presence of a patrol ship if they consider reliable their coverage, while a fishing vessel probably will try to stand away from Navy ship to don't waste time in inspections. So it is not enough to collect historical data on traffic, and it becomes necessary to create dynamic behavior models for the traffic itself. This paper addresses this issues with special attention to the context of piracy even if the proposed techniques could be easily applied to other contexts in Maritime Interdiction or in other sectors,

2. THE APPLICATIVE CONTEXT

Modern Piracy is a reality that, even if mitigated in some area along the most recent years, is still present and dangerous over many different world regions and requires very big efforts for being properly addressed; indeed sometime the solutions could result not sustainable in terms of costs making this as trade off game between Nations and Pirates. This phenomena was arising back along last 25 years: since 1990s capturing ships, holding them and their crews for ransom and stealing what is on them, has been carried out by armed groups acting mostly in the territorial sea. By the international definition these groups are called piracy which consists of "any illegal acts of violence or detention, committed for private ends by the crew or the passengers of a private ship or aircraft and directed on the high seas against another ship or aircraft, or against persons or property on board such ship or aircraft" [42]. Piracy is a phenomenon grown in the absence of a government able to enforce the law, and this is a common situation in the Indian Ocean. In

Somalia, for example, during recent years pirate activity absorbed a growing number of people and became ever intense, up to a maximum of 160 attacks in 2011 [28].

Taking advantage of the continuous lack of an effective government and of political and armed fights going on in Somalia, pirates became a serious menace in the area between the Horn of Africa and the Arabian peninsula [41]. Although from 2011 the Somali attacks have decreased, piracy remains a threat for maritime traffic as already anticipated. In fact in the first six months of 2015, the IMB (International Maritime Bureau) reported 134 pirates boarded on ships worldwide, which have increased in comparison with the 116 of the corresponding period in 2014. To have an idea of the danger let's highlight that in 2015 pirates boarded 106 vessels to steal crew belongings, money and other ship's property, attempted 15 attacks and hijacked 13 vessels. Therefore only 15 out of 134 boarding failed. Only in South-East Asia there was in a average one attack every two weeks, and about 38% of the 13 hijacks were carried out in this area [29]. These facts reveal that international attention must still consider piracy as a threat for international maritime routes.
Furthermore, piracy has a cost for international finance. In 2008 the overall costs of piracy in the Pacific and Indian Oceans alone were estimated up to US$16 billion [25]. In 2014, although there is no estimation, the cost remains high considering that 245 attacks were reported, only 48 cases less than 2008 [28]. The human costs are remarkable, not only for the loss of lives but also for the trauma inflicted upon hostages and their families. So it remains an aspect to not underestimate, both for human and financial costs. To combat this incessant threat, government and researchers have developed various measures to put piracy under control and to mitigate the risks it implicates.
The IMB has instituted some guidelines to enforce defense on cargos and ships and has identified some maneuvers to escape dangerous situations

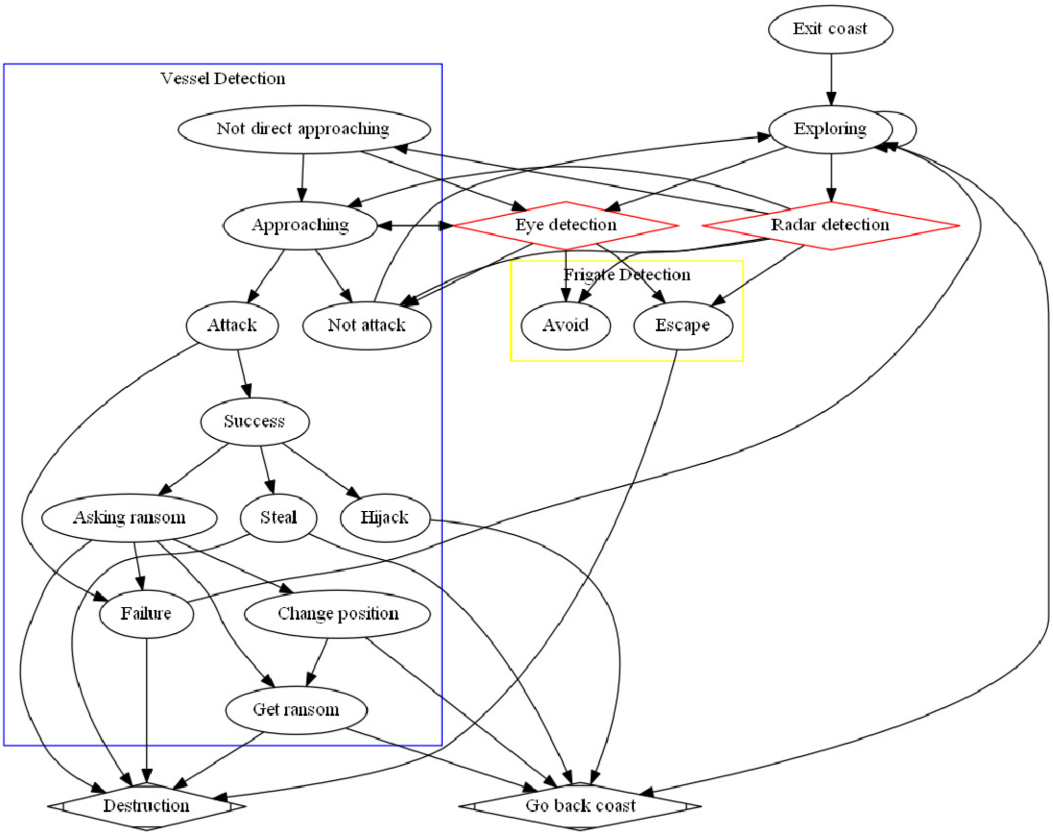

Figure 1: Example of Model of the Pirate Behavior

3. M&S AND PIRACY

In addition, researchers are studying different strategies to prepare naval fleets to defend sailing routes from pirates [15]. It is common to use a simulator that could experiment and train maritime operators, with different solutions to diverse scenarios [7,16,27,37, 43, 45, 46]; by the way the interoperable simulation technologies here proposed have been successfully used also in commercial application devoted to improve training, safety and security [12, 47]. Although simulation has long been used for naval warfare purposes, there is little work on modeling civilian maritime traffic, one of these is the Matrics project [22]. This project models the behavior of transport ships near the Canadian shore; in this case the used model is based on fluid mechanics and it doesn't represent vessel interactions and other complex structures in maritime traffic.

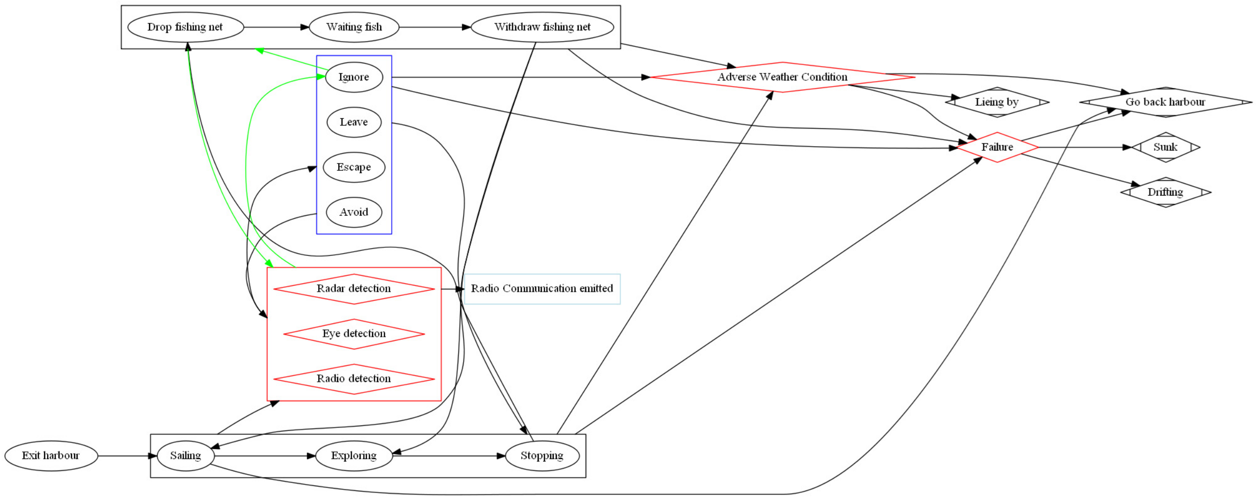

Figure 2: Fishing Boat Behavioral Model

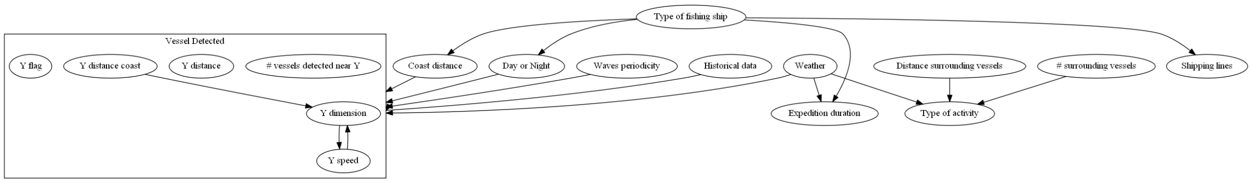

Figure 3: Interactions among Variables and Boundary Conditions

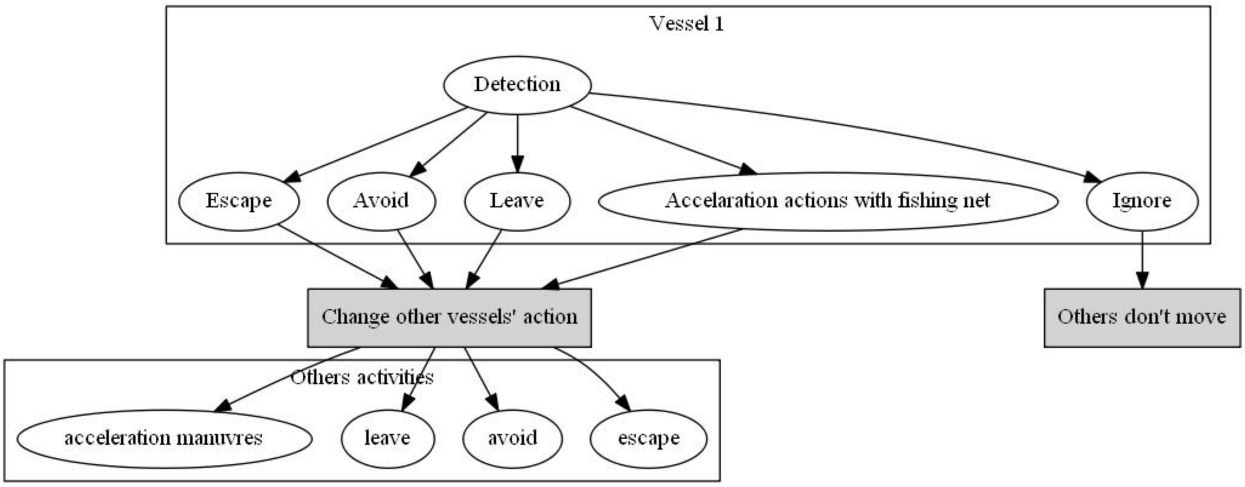

Figure 4: Example of Model Evolution based on Presences of other Ships

By applying agent-based techniques, Jakob and colleagues developed a simulation to detect and, in case of necessity, suppress piracy. They use Google Earth-based front end to visualize the outputs [30, 31]. They follow the example of numerous agent-based simulations available for other traffic and transportation domains, such as air and road traffic [34,35]. The use of planning could be based on multiple approaches and methodologies and its combination with simulation provide further capabilities to address complex phenomena affected by stochastic factors [11, 23, 25, 32].

Indeed discrete event stochastic simulation was extensively used by the authors for addressing piracy in research projects and initiatives [7, 13]; PANOPEA was created to study these phenomena respect the agility of NATO Net-Centric Command and Control Maturity Model (N2C2M2). [6]

This model was applied to Aden gulf scenarios reproducing several thousands of surface boats, all cargo traffic and different coalition of military vessels by using Intelligent Agents (IA) embedding complex Human Behavior Models (HBM) [8]; indeed these IA are a tailored marine NCF (Not Conventional Framework) developed by Simulation Team by using IA-CGF models (Intelligent Agent Computer Generated Forces) for reproducing human behavior in different contexts [4,5,9, 14].

In addition, several other simplified models were from PANOPEA (Piracy Asymmetric Naval Operation Patterns modeling for Education & Analysis) for being applied for other purposes in piracy simulation as collaboration between Simulation Team and other

partners [18]; these models usually don't simulate the details of all the traffic including the small medium size boats; for instance MALICIA (Model of Advanced pLanner for Interoperable Computer Interactive Simulation) was created as support for tactical decisions and integration a resource and operational planning optimizer and a scenario analysis tool as well as a special set of algorithms to be used as decision support system [17]; another simplified model derived from the proposed case was JAMS2 (Joint Advanced Marine Security Simulator) customized for being used within EKOE (Environment Knowledge and Operational Effectiveness) to test an innovative evolutionary system devoted to define patrolling strategies over a fixed set of assets [21].
Starting from the idea that navy forces could be trained with a simulator, it is necessary to better model both maritime traffic and pirate activity.
The authors carried out researches for using MS2G (Modeling, interoperable Simulation and Serious Games) for training in different contexts including piracy and to evaluate complex scenarios [16, 20]. In this paper it is presented the study of the possible movement of fishing and cargo ships with pirate ones at sea. We developed some conceptual models to understand how they move and how they interact with each other. To model this interaction we hypothesized that some biological model, such as a prey-predator model at sea, in combination with game-theory could represent well this kind of relations. Pirates are described as predators and ships as potential prey. So ships are represented in an agent-based or individual-based model (IBM), with each agent carrying information about its position, its type of vessel and other information, as in a biological model every agent wears its physiological state and its species.
So first of all we identified all possible behaviours of all the actors and we put them in relation with each other in a conceptual model (for example Fig. 1). Secondly, we analysed the relations existing among different vessels corresponding to autonomous agents in a multi-agent system. Vessels in the system are capable of moving freely within the spatial boundaries of surface waters while interacting with the maritime environment and other vessels (either directly-via communication or indirectly-via environment).
This study was used to implement behavioral models within simulators piracy as dynamic solution to address these complex problem; indeed the authors developed different simulators dealing with this phenomenon derived from PANOPEA for different applications, including MALICIA and JAMS2 [17,21]; in this paper it is proposed the use of HBM to carry out the experimentations on Simulation Team Piracy simulator for evaluating the effectiveness and efficiency of anti-piracy operations. Indeed these simulators are derived from PANOPEA and are stochastic, discrete event, interoperable agent driven simulators based on IA-CGF. In general the IA-CGF are able to interoperate through use of HLA Standard (High level Architecture) and are available to be federated with other systems and models; therefore some of these simulators don't enabled such functions and adopt asynchronous web services for exchanging scenario Data Base [33].

4. THE PROPOSED CONCEPTUAL MODEL

In this work it is presented a set of models to be embedded in the agents devoted to direct the simulation that could be applied to pirate simulators derived from PANOPEA; indeed the general framework proposed Is based on discrete event stochastic simulation, under this paradigm intelligent agents (IA) are used to control the vessels and to reach to their perceptions and their own scenario awareness.
The marine IA-CGF control the vessels and reproduce the dynamic nature of the maritime traffic in real world as well as the behaviors of small medium size boats such as fishermen and pirates under coverage.
The solution generated by this agent driven simulation is applying a predator-prey model in water where ships considered as fishes are "hunted" by predators that are pirates. An agent based model was used to create the different species' behavior. The mechanism that will choose the right behavior for the predator could be evolved by using Genetic Algorithms in order to optimize the related parameters (e.g. threshold distance for the attack, tolerance invading safe corridors, acceptable weather condition and parameters defining the size of the attack team and their coordination level).
In this model the pirates as a predator sail around randomly and if they see a prey-vessel in their vision radius they try to catch the closest one by sailing at maximum speed towards it. In contrary as a prey do, if vessel spots a predator it will immediately goes away with its maximum speed; obviously each vessel is characterized by its own parameters defining speed, maneuverability, sea keeping, sensor range, resolution, mimetic capabilities, etc. This kind of relation is pretty close to the simplest predator-prey model; moreover in a biological system, as a result of the presence of predator "A" through an area, the prey may change its behavior in ways that make themselves more difficult to be captured by predators. This may involve changes in the group's behavior, such as greater alertness or reduction of activities that increases risk of predation for example, advertising and feeding [24]. In our case for example fishermen could change the duration of the fish expedition or the period where nets are in the water. Here it's presented all type of behavior that all the agents of the simulation could perform.
It is pretty important to include in these models the the use of human behavior modifiers considering influence of stress, fatigue, aggressiveness and fear on agent decision making; this was experienced extensively by Simulation Team in multiple context and scenarios [8].
The following types of vessels are presented in the simulation:

- merchant ships or cargo identified as large ocean-going vessels carrying cargo over long distances on international maritime routes, primary targets of pirate attacks;

- pirate ships are vessels of different types and sizes operating close to transport lines, where they are looking to attack, board and hijack cargo ships; pirate ships usually are large "motherships" acting as floating bases from which skiffs[1] are launched to attack;
- fishing ships are vessels used to fish; they could be a possible target for pirates.
- navy frigates are military vessels operating in piracy-affected areas and capable of armed action to neutralize pirates.

In this paper the model for the military vessels is not analyzed in details, assuming that the patrol is controlled by the genetic planning optimizer; indeed the others object behavior could be further developed based on the specific scenario [10].
Indeed the predators are used to do much more than just move as response to the behavior of their prey, so, in the same way, the pirates perform diverse behavior and not only searching and boarding vessels along they operates; in similar way the IA are adopting behaviors to support their mimetic among fishing boats as cloaking procedures. Nevertheless there are many alternatives that could be evaluated and simulation allows to evaluate and investigate their impact on cargo vulnerability as well effectiveness of possible counter measures from the military vessels. Hereafter it is proposed examples of behavior models.

Pirate Model
Historically, in biology, studies have been focused on prey behavior that treats predators as unresponsive subjects rather than participants in a behavioral interaction. This oversight has not only led to an incomplete view of behavioral interactions between predators and preys, but has also obscured an entire class of such interactions that occurs at large spatial scales. Here a detailed analysis is presented about pirates behavior considered as a predator.
Usually pirates move from the coast with a "mothership", that could be a merchant ship or a fishing vessel. That ship enables pirates to operate over a much larger area and it is less affected by the weather. It carries arms, fuel, support material and attached skiffs which are used for attacking ships. In general there are two skiffs that are small high speed (up to 25 knots) open boats that facilitated the ship approach. To simplify the model, the mothership and the skiffs are both considered as a unique structure, that goes out of the coast "exit coast" and explores the sea until a vessel is intercepted. After this, pirates start the approach (that could be direct or indirect to misdirect the ship) and they chose to attack or not attack, depending on the kind of ship, weather conditions, or type of defense. The attack is conducted with the skiffs alongside the ship being attacked to enable one or more armed pirates to climb onboard. Pirates frequently use long lightweight ladders and ropes to climb up the side of the ship. Once onboard pirates will generally make their way to the bridge to try to take control of the vessel usually using small fire arms. Once on the bridge, pirates could start some different attacks:

- "steal" is when pirates go up to the ship to steal what they transport or the money in the strongbox;
- a "hijack" is when pirates have boarded and taken control of a vessel against the crew's will;
- "asking ransom" is when pirates ask ransom making the crew or only the master hostage or the entire vessel, in this case they usually move the vessel in a controlled area.

In the model only the macro movements of the pirates on skiffs or the ship attacked were represented.
Figure 1 proposes the synthesis of their movement model; indeed in the proposed representation of the model, the statuses are presented as dark circles (transition status) or diamonds (absorbing status) while the arrows are the alternative possible transitions; the red diamonds are events that could influence behaviors; the large blue square encapsulates all behaviors related to a ship detection are, while the yellow one includes those in relation with the military vessels.
Indeed after the attacking the ship, the pirates could fail in capturing it: this could be due to the intervention of navy vessels and neutralization of pirates; therefore the attack failure could happen also for other reasons such as cargo self-defense procedures or weather conditions; in these case the pirates could turn back on their stand-by operative modes and continue the sea exploration for potential preys. In this model the situation awareness of the pirates based on direct or indirect information on the military vessel operations and positions could lead to escape actions in explicit or concealed way based on the boundary conditions (e.g. weather, info available, other vessels into the area) related to the current dynamic situation (e.g. current distance, visibility, distance to the coast, etc.).

Fishing Model
In similar way to pirate behavioral model, also the fishing boat model describes the statuses and reactions to evolving situation: the boats sail out of the harbor to fish; in case of interception of some potential coast guard ship or military vessels, by radar, radio or eye detection, the boat-agent could choose to avoid interception, escape (sail full sea speed or high speed to prevent interception), leave (sail out softly at low speed) or ignore. It will depend on condition at contour, such as ship identification, flag, direction of the ship etc. These behaviors are pretty similar to that one of the pirates; so it is evident that this increase the military vessel difficulty for identifying pirates and avoiding false alarms. Indeed the fishing boats are almost impossible to be discriminate from pirates in terms of physical and kinematic features (e.g. speed,

1 A skiff is a small, flat-bottomed open boat with a pointed bow and a flat stern. It was originally developed as an inexpensive option for coastal fishing. Skiffs used by pirates are powered by outboard motors.

size, shape, model and type), but the not cooperating behaviors of fishermen trying to avoiding waste of time with inspections combined with the mimetic behavior of the pirates contribute to make even more difficulty the anti piracy missions. In figure 2 the model is proposed representing possible conditions as dark circles (transition statuses) and diamonds (absorbing statuses); indeed also in this case the red diamonds corresponds to events influencing the behaviors, while the big blue square addresses all behaviors dealing with vessel detection. The green arrows proposed by the figure correspond to mean that this way is almost unique possible (very high probability), corresponding to the fact that if vessel detects a navy ship when its nets are in the water it could only wait until all the nets are back on the ship to activate leaving procedures or similar behaviors. In case that the fishing ship is dropping, withdrawing nets, or waiting for the fish, it has a obligate choice to ignore any sighting because it is considered that the loss of the nets has too elevated cost. In this case the ship could only accelerate the maneuvers but since the process is not concluded, it has to wait. In addition here we represent the case of adverse weather conditions where ships could sink or drift or go back to the harbor.

Cargo Model

Cargo behaviors are aiming to reduce two opposite target functions addressing traveling time/cost and risk while moving in the dangerous area; due to these reasons the cargo are using their scenario awareness to avoid pirates and to adopt procedures to prevent boarding risks; in case they suspect presence of pirates they could request support to the military vessels considering reaction time and probability of request acceptance based on dynamic situation. A boat is evaluated as pirate based on its behavior and characteristics considering positions, distance, course, presence of other boats, boat identification and flag, etc. In fact one of the most effective ways to defeat a pirate attack is using speed to try to outrun the attackers and make it difficult to board. There have been no reported attacks when ships have been proceeding at over 18 knots. It is possible however that pirate' tactics and techniques may evolve to enable them to board faster moving ships by using multiple attacks, even if it hasn't happened yet [25].

Boundary Conditions

In this section, variables that are independent from the behavioral models, but influencing them, are described as well as their interconnection.

Indeed some very important boundary conditions are weather conditions, day time, coast distance and historical data. In fact the first two determinate if ships could stay and operate at sea; these factors are continuous; in addition the simulation allows to consider that the visibility conditions due to sun, moon light, fog, rain along day and night. The distance from the coast is another particular relevant variable because piracy attacks usually don't happen very far from the coast: it will be too dangerous for the mothership and risky also in case of success.

Historical data could be useful to determine the "High Risk Area" defined as the area where pirates' activities and/or attacks have taken place. Usually attacks have taken place at the farthest of the High Risk Area [41].

These variables affected the pirates' behaviors; indeed the level of pirates' activity varies greatly due to weather conditions and activity by military forces. Pirates' business generally is reduced in areas affected by the South West monsoon, and it is increased in the period following the monsoon.

As a prey behavior, pirate movements could change in relation of how many vessels are in proximity as well as based on the cargo density. So another variable is related to the characteristics of surroundings vessels such as distance, dimension, activity, flag etc.

In Figure 3 the interaction among variables and boundary conditions is proposed for a specific example where weather conditions influence the expedition duration etc..

Social Behavior

Although behavior is often examined within a dual relation, behavioral interactions are also influenced by the broader social context such as the presence of other vessels as partially anticipated. In fact interactions with neighbors vessels and boats could be an useful source of information about the surrounding environment influencing the behavioral decisions. This phenomena is well known also in the biological systems where it is demonstrated that individuals adjust their behavior when neighbors are present. More specifically the presence of neighbors influences defense against predators both in fish and sea birds [26, 36, 40].

In parallel with biological systems, we expect also that individuals alter their behavior based on evaluation of surrounding groups, in order to improve their potential in terms of "fitness" that, in this case, is represented by avoiding pirates attacks. In natural ecosystems, this is particularly effective for territorial species that have long-term relationships with neighboring groups [26]. Indeed similarities could be find with fishing boats that could be also considered stable since they always stay mostly in the same areas to practice their fishing activities; due to these reasons pirates and fish boats are expected to know the behavioral models of the entities on the area making more simple for them to avoid interception by military ships by hiding among other small medium size boats as well by knowing usual behavior of coast guards.

For most of the time, each vessel pursues its individual goals, but there are also situations where multiple vessels interact dynamically. Such interactions are characterized by different nature; for instance there are non-cooperative interaction such as that one when a pirate attack a cargo or when boats moves away to avoiding inspections and wasting time with coast guards and warships; there are also collaborative interaction such as when navy assets are collaborating within one or different coalition to achieve pirate interceptions or when merchant vessels' calls for help from navy vessels. Indeed the collaboration to defend each other results as an effective way to fifth piracy. The models proposed by the authors are characterized by these aspects, so in case of presence of others vessels the behavior change; in facts in a High Risk Area, ships have a major benefit to stay in contact (in close proximity or by radio) with others to improve their possibilities to avoid pirates.

5. BEHAVIORAL MODEL EFFECTS ON SIMULATION

The effect of behavioral models is measured by the simulator in terms of overall performance respect multiple variables

$$CIT(t) = \frac{nTId(x)}{n}$$

$$CIT_{AVG}(t) = \frac{\int_t^{t+dt} nTId(x)dx}{n \cdot (dt)}$$

$$CIT_{min} = \min\left(\frac{nTId(t)}{n}\right) \forall t \in (t_0, t_{end} - dt)$$

$$CIT_{max} = \max\left(\frac{nTId(t)}{n}\right) \forall t \in (t_0, t_{end} - dt)$$

$$CIT_{STD}(t) = \sqrt{\frac{\int_t^{t+dt} \left\{\frac{nTId(x)}{n} - \left[\frac{\int_t^{t+dt} nTId(y)dy}{n \cdot (dt)}\right]\right\}^2 dx}{dt}}$$

CIT(t)	Instantaneous Scenario Awareness measured in terms of percentage of correct identifications over total number of targets
CIT_{AVG}(t)	Average percentage of correctly identified target over a time frame
CIT_{min}	Minimum percentage of correctly identified target
CIT_{max}	Maximum percentage of correctly identified target
CIT_{STD}(t)	Standard Deviation on the percentage of correctly identified target over a time frame
nTId(t)	number of targets correctly identified at t time
t_{end}	Simulation Ending Time (e.g. 7 weeks)
t_0	Time to start data collection the Scenario Awareness

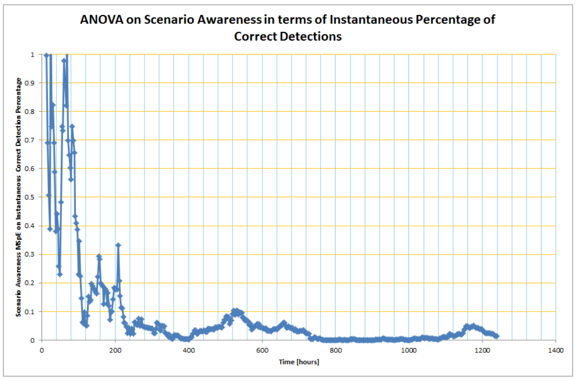

Figure 5: ANOVA on Instantaneous CIT

n	number of targets
dt	amplitude of the time window used to estimate average scenario awareness, in this case it was used a 3 days setting

Obviously these target functions are just an example among many others evaluated by the simulator (e.g. reactiveness, reliability, coverage, resilience etc.); in particular these ones provides an evaluation of the dynamic situation of the scenario awareness.
In order to evaluate the models it was fundamental to adopt VV&A (Verification, Validation and Accreditation) as set of critical steps along the whole model development process [2]; indeed in behavioural models it is very difficult to collect data related to real case studies and it is necessary to conduct experimental analysis and dynamic validation [1]; indeed in the paper are shortly described the main dynamic VV&A used during experimentation; in this case ANOVA (Analysis of Variance) was used through evaluation along time of the variance of the experimental error [39].

$$MSpE\_CIT_{AVG}(t) = \frac{\sum_{i=1}^{r_0}\left[CIT_{AVG}(t) - \frac{\sum_{j=1}^{r_0} CIT_{AVG}(t)}{r_0}\right]^2}{r_0 - 1}$$

$$MSpE\_CIT_{STD}(t) = \frac{\sum_{i=1}^{r_0}\left[CIT_{STD}(t) - \frac{\sum_{j=1}^{r_0} CIT_{STD}(t)}{r_0}\right]^2}{r_0 - 1}$$

r_0	number of replications to be used for evaluating influence of stochastic factors

In figure 5, 6 and 7 the ANOVA is applied by analyzing the temporal evolution of the Mean Square pure Error (MSpE); the stabilization of confirms the validity of the simulator and allow to estimate the confidence band respect the influence of stochastic variables; the stabilization period in this case is around 30 simulated days.

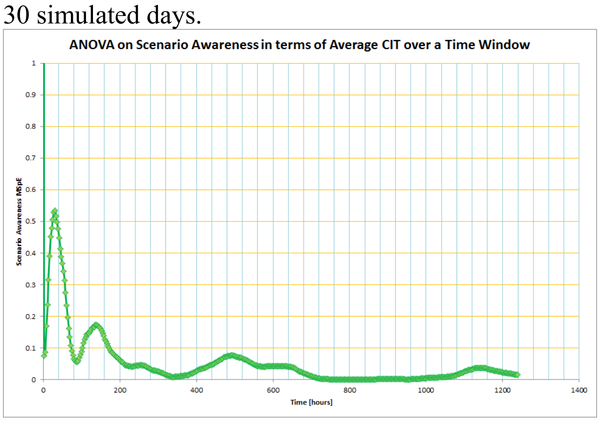

Figure 6: MSpE on average CIT

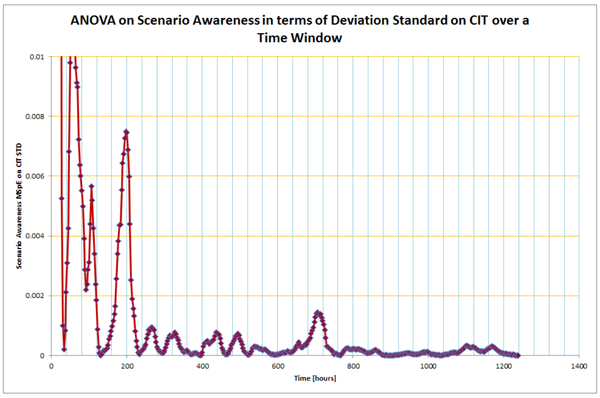

Figure 7: MSpE on CIT Standard Deviation

The implementation of the model in Java using Simulation Team libraries allows to complete a simulation within few seconds for such period confirming the potential for using such approach for extensive experimental analysis.

6. CONCLUSIONS

The current models represent and interesting approach in modeling complex behaviors by considering mutual reaction among rational and emotional entities in dynamic environments; the use of biological examples as inspiration to define the models of the pirates was effective in creating a more realistic evaluation of countermeasures and their effectiveness considering the mimetic strategies applied by the pirates and the non cooperative behavior of small medium size fishing boats. The different models developed could be used to populate different scenarios and to support testing new technological solutions and/or operational procedures for piracy as well for other maritime contexts; in addition this study confirmed the validity of the IA-CGF and their capabilities further extending them with these new HBM. The authors are planning to use further develop these models to address thread networks and other complex contexts through extensive use of the behavioral models within MS2G paradigm.

REFERENCES

[1] Amico Vince, Guha R., Bruzzone A.G. (2000) "Critical Issues in Simulation", Proceedings of Summer Computer Simulation Conference, Vancouver, July

[2] Balci O., Glasow P., Muessig P, Page E.H., Sikora J., Solick S.,Youngblood S. (1996) "DoD Verification, Validation and Accreditation (VV&A) Recommended Practices Guide", Technical Report Defense Modeling and Simulation Office, Alexandria, VA, November

[3] Bruzzone A.G., Cunha G.G., Landau L., Merkuryev Y. (2004) "Harbour and Maritime Simulation", LAMCE Press, Rio de Janeriro, ISBN 85-89459-04-7 (230 pp)

[4] Bruzzone A.G. (2008) "Intelligent Agents for Computer Generated Forces", Invited Speech at Gesi User Workshop, Wien, Italy, October 16-17

[5] Bruzzone A.G., Cantice G., Morabito G., Mursia A., Sebastiani M., Tremori A. (2009) "CGF for NATO NEC C2 Maturity Model (N2C2M2) Evaluation", Proceedings of I/ITSEC2009, Orlando, November 30-December 4

[6] Bruzzone A.G, Massei M., Madeo F. (2011) "Experimentation of Marine Asymmetric Scenarios for testing different C2 Maturity Levels", Proceedings of 16th ICCRTS, Quebec City, Canada, June

[7] Bruzzone, A.G., Massei, M., Tremori, A., Longo, F., Madeo, F., Tarone, F. (2011) "Maritime security: emerging technologies for Asymmetric Threats", Proceedings of the European Modeling and Simulation Symposium, EMSS2011 (Rome, Italy, September 12-14, pp.775-781

[8] Bruzzone, A.G., Tremori, A., Massei, M., (2011) "Adding Smart to the Mix," Modeling, Simulation & Training: the International Defence Training Journal, 3, 25-27

[9] Bruzzone A.G., Massei M., Tarone F., Madeo F. (2011) "Integrating Intelligent Agents & AHP in a Complex System Simulation", Proceedings of the international Symposium on the AHP, Sorrento, Italy, June.

[10] Bruzzone A.G., Tremori A., Merkuryev Y. (2011) "Asymmetric Marine Warfare: Panopea A Piracy Simulator For Investigating New C2 Solutions", Proc. of International Conference on «Simulation and complex modelling in marine engineering and marine transporting systems» – SCM MEMTS, pp. 32-49.

[11] Bruzzone A.G., Tremori, Bocca E., A., Madeo F., Tarone F., Gazzale G. (2011) "Modeling & Simulation as Support for Decisions Making in Petrochemical Marine Logistics" Proceedings of HMS2011, Rome, Italy, September

[12] Bruzzone A.G., Fadda P, Fancello G., Massei M., Bocca E., Tremori A., Tarone F., D'Errico G. (2011) "Logistics node simulator as an enabler for supply chain development: innovative portainer simulator as the assessment tool for human factors in port cranes", Simulation October 2011, vol. 87 no. 10, p. 857-874, ISSN: 857-874, doi: 10.1177/0037549711418688.

[13] Bruzzone A.G., Massei M., Solis A., Poggi S., Bartolucci C., Capponi L. (2013) "Serious Games as enablers for Training and Education on Operations over Off-Shore Platforms and Ships", Proceedings of Summer Computer Simulation Conf., Toronto, Canada

[14] Bruzzone A,G. (2013) "Intelligent agent-based simulation for supporting operational planning in country reconstruction", International Journal of Simulation and Process Modelling, Volume 8, Issue 2-3, pp.145-151.

[15] Bruzzone A.G. (2013) "New Challenges for Modelling & Simulation in Maritime Domain", Keynote Speech at SpringSim2013, San Diego, CA, April

[16] ruzzone A.G., Simonluca L, Ferrando A., Poggi D., Bartolucci C., Nicoletti L., Franzinetti G. (2013) "Serious Game for Multiuser Crew Collaborative Procedural Training and Education", Proc. of I/ITSEC, Orlando, FL

[17] Bruzzone A.G., Longo F., (2014) “Interoperable Interactive Simulation for Advanced Planning”, Simulation Team Technical Report, Genoa, September

[18] Bruzzone A.G., Corso M., Longo F., Massei M., Tremori A. (2014) “Data Fusion and simulation as decision support system in naval operations”, Proc. of HMS, Bordeaux, France, September

[20] Bruzzone A.G., Massei M., Tremori A., Longo F., Nicoletti L., Poggi S., Bartolucci C., Picco E., Poggio G. (2014) "MS2G: simulation as a service for data mining and crowd sourcing in vulnerability reduction", Proceedings of WAMS, Istanbul, September

[21] Bruzzone A.G., Tremori A., Corso M., Piccini I. (2013) “Results of Threat Simulations in the CMRE Asset Allocation Decision Support Tool”, CMRE Technical Progress Report, La Spezia, Italy, December

[22] urton S., Y. Gauthier, and J. Greiss (2007) “MATRICS: A Maritime Traffic Simulation”, tech. report, Defense R&D Canada, Center for Operational Research and Analysis

[23] Cassandra A., Kaelbling L., and Littman M. (1994) “Acting optimally in partially observable stochastic domains”, Proceedings of the National Conference on Articial Intelligence (AAAI) , pages 1023-1028, Seattle, WA, August

[24] Charnov E.L., Orians G.H., Hyatt K., (1976) “Ecological Implications of Resource Depression”, The American Naturalist, Vol. 110, No. 972, pp. 247-259

[25] ilpin R. (2009) “Counting the Costs of Somali Piracy,” working paper, US Inst. of Peace, 2009.

[26] Hellmann J.K. and Hamilton I.M. (2014) “The presence of neighbors influences defense against predators in a cooperatively breeding cichlid”, Behavioral Ecology 25, pp. 386–391.

[27] Hays R.T., Vincenzi D.A.(2000) “Fleet assessments of a virtual reality training system”, Military Psychology, Vol. 12, Issue 3, Pages 161-186

[28] CC - IMB (Commercial Crime Services - International Maritime Bureau), (2014) “Piracy and Armed Robbery against Ships”, report 2008 - 2014, ICC IMB Piracy Reporting Centre (PRC), London.

[29] CC - IMB (Commercial Crime Services - International Maritime Bureau), (2015) “Piracy and Armed Robbery against Ships”, report for the period 1 January to 30 June 2015, ICC IMB Piracy Reporting Centre (PRC)

[30] akob M., Vanek O., and Pěchouček M., (2011) “Using Agents to Improve International Maritime Transport Security”, Intelligent Systems, IEEE

[31] akob M., Vanek O., Hrstka O. and Michal chouček, (2012) “Agents vs. Pirates: Multi-Agent Simulation and Optimization to Fight Maritime Piracy”, Proceedings of 11th International Conference on Autonomous Agents and Multiagent Systems - Innovative Applications Track, AAMAS, Valencia, Spain, June

[32] Koenig S. (1991) “Optimal probabilistic and decision-theoretic planning using Markovian decision theory”, Technical Report UCB/CSD 92/685, Master's thesis, Computer Science Department, University of California at Berkeley, Berkeley CA

[33] Kuhl F., Weatherly R., Dahmann J. (1999) "Creating Computer Simulation Systems: An Introduction to the High Level Architecture", Prentice Hall, NYC ISBN: 0130225118

[34] Manish Jain, Jason Tsai, James Pita, Christopher Kiekintveld, Shyamsunder Rathi, Fernando Ordonez, Milind Tambe, (2010)“Software Assistants for Randomized Patrol Planning for the LAX Airport Police and the Federal Air Marshal Service,” Interfaces, vol. 40, no. 4, pp. 267–290.

[35] Pěchouček M., Sislak D. (2009) “Agent-Based Approach to Free-Flight Planning, Control, and Simulation” IEEE Intelligent Systems, vol. 24, no. 1, pp. 14–17

[36] Kazama K, Watanuki Y. “Individual differences in nest defense in the colonial breeding Black-tailed Gulls, Behav Ecol Sociobiol. 64, 2010, pp. 1239–1246.

[37] Massei, M., Tremori A., (2011) "Mobile Training Solutions Based on ST_VP: an HLA Virtual Simulation for Training and Virtual Prototyping within Ports", Proc. Of SCM MEMTS, St.Petersburg, Russia

[38] McLeod J. (1982) "Computer Modeling and Simulation: Principles of Good Practice", SCS, San Diego

[39] Montgomery D.C. (2000) "Design and Analysis of Experiments", John Wiley & Sons, New York, 588-592

[40] Schädelin F.C., Fischer S., Wagner R.H., (2012) “Reduction in predator defense in the presence of neighbors in a colonial fish”, PLOS One, 7:e35833.

[41] KMTO (2011) “Best Management Practices for Protection against Somalia Based Piracy - Suggested Planning and Operational Practices for Ship Operators and Masters of Ships Transiting the High Risk Area”, booklet, Wither Publishing Group Ltd, Edinburgh, UK

[42] United Nations (1982) “Art. 105 UNCLOS”, United Nations Convention on the Law of the Sea, NYC

[43] Wiedemann J. (2013) "Naval Forces", Special Issue 2013, Vol. XXXIV ISSN 0722-8880, 5-59

[44] Ören, T., Longo, F. (2008). Emergence, anticipation and multisimulation: Bases for conflict simulation. Proceedings of the 20th European Modeling and Simulation Symposium, EMSS 2008, pp. 546-555

[45] Longo, F. (2012). Supply chain security: An integrated framework for container terminal facilities. International Journal of Simulation and Process Modelling, Volume 7, Issue 3, pp 159-167.

[46] Longo, F., Huerta, A., Nicoletti, L. (2013). Performance analysis of a Southern Mediterranean seaport via discrete-event simulation. Strojniski Vestnik/Journal of Mechanical Engineering, 59 (9), pp. 517-525.

[47] Longo F., Chiurco A., Musmanno R., Nicoletti L. (in press). Operative and procedural cooperative training in marine ports. (Articles not published yet, but available online), DOI: 10.1016/j.jocs.2014.10.002.