# DISCRETE EVENT SIMULATION FOR VIRTUAL EXPERIMENTATION ON MARINE DECISION SUPPORT SYSTEM

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**ABSTRACT**

This paper 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 authors included description of the proposed architecture that guarantees flexibility in terms of interoperability with other systems.

## INTRODUCTION

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 defense 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; so it is evident these elements are pushing forward the development and adopting of new generations of DSS (Decision Support Systems) able to integrate simulation and other planning methodologies and optimization tools. These conditions are also present in defense 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 solution for such complex non-conventional scenarios requires the ability to evaluate several alternative plans against courses of action (Richards, Bellingham, Tillerson, & How, 2002; Bruzzone et al. 2011a).
As anticipated Decision Support Systems fulfill their potential by being integrated with modeling 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 planner and to measure their resilience to 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 the present paper the authors propose this approach for supporting patrol planning over an oceanic area for anti-piracy missions. In this paper, it is proposed the integration a route optimizer based on genetic algorithms to increase the probability to prevent pirate actions with a stochastic discrete event simulator focused on evaluating the fitness and supporting the decision maker in finalizing the plan. The present paper 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.

## 1 THE SIMULATOR AND THE PATROLLING PATH OPTIMIZER

In the present paper the authors propose a solution for supporting patrol planning over an oceanic area in 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). Indeed JAMS2 (Advanced Marine Security Simulator) is a simplified version derived from PANOPEA simulator 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 the 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. In the case studied for this case-study the mission environment 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 behavior 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, to playing the role of the "real world" to test and validate the proposal, it could also be used to conduct what-if analysis directly by the decision maker. As anticipated the mission environment corresponds to the West Indian Ocean 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; so it is designed for being interoperable through High Level Architecture Standard (HLA); therefore 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).
Currently the vessels and boats are modeled as surface elements (friends, foe, neutral) characterized by dynamic behavior. 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 of risks and stochastic factors is achieved by replicating JAMS2 simulation runs just by changing random seeds to finalize the ANOVA. JAMS2 results 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 (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.

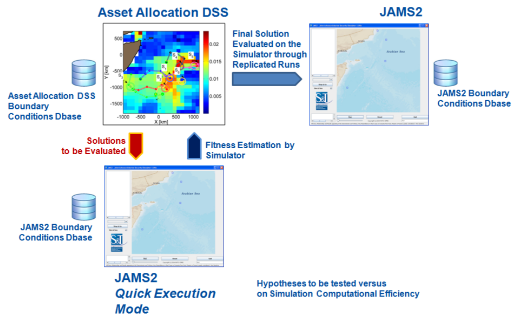

**Figure 1:** JAMS2 Dynamically Used With the Asset Allocator

Therefore in future by enabling JAMS capability to be connected to an HLA federation could allow to operate both as stand-alone and federated with other simulators.
The Graphical User Interface (Figure 2) 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 run in terms of dynamic behavior 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 Montecarlo techniques to generate discrete events and corresponding actions/behaviors. Threats and false alarms adopt stochastic behavior reacting dynamically to assets evolution; indeed Intelligent Agents (IA) are used to reproduce sophisticated behaviors for small/medium size boats in order to react to the patrol actions and policies within the area suggested by the AADSS.

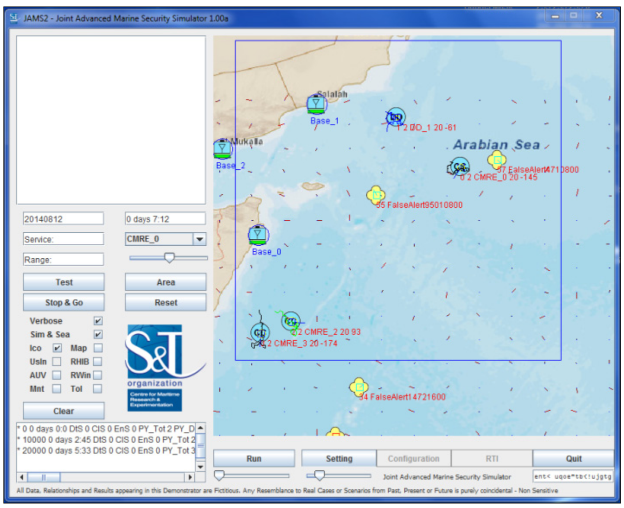

**Figure 2**: JAMS2 GUI

In a similar way the agents controlling the patrolling vessels adopt their different behaviors based on their situation awareness and their specific characteristics; in general the IA controlling the patrol units could decide among different alternatives 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

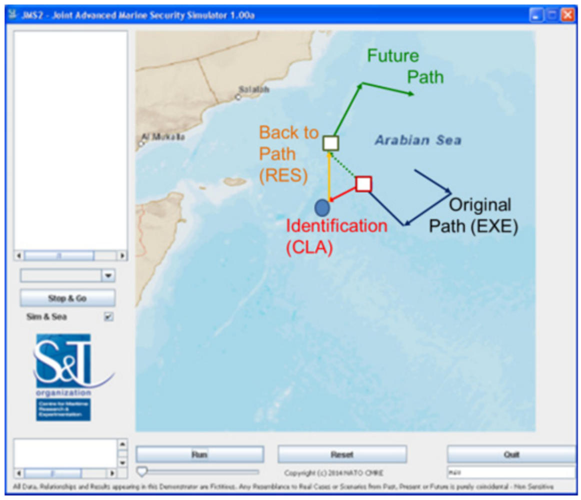

**Figure 3**: Asset Undertaken Actions and Operating Modes

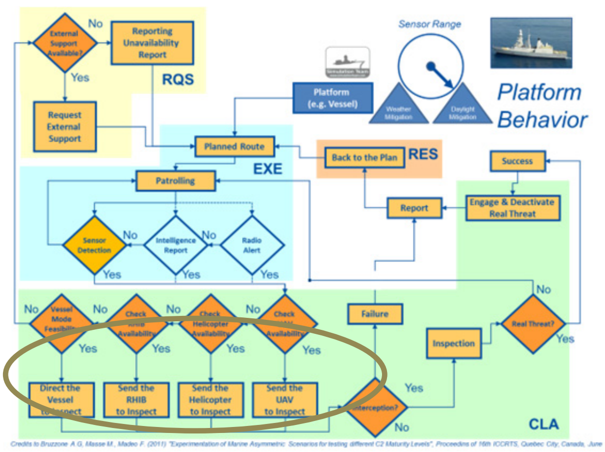

**Figure 4**: JAMS2 Platform Behavior

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Figure 3 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 resources; so when it is necessary to assign some resources to inspecting a boat based on the available resources and target distance, the agent selectd the proper choice (Figure 4).
The capability to simulate different shared resources in the scenario is necessary to create complex autonomous

behavior; 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 TARGET

Targets represent a possible risk source. Indeed the behavior, 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 Montecarlo 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 behavior
- NRE: Non-reactive behavior
- COP: Cooperative behavior
- NCP: Non-cooperative behavior
- FOE: Aggressive behavior

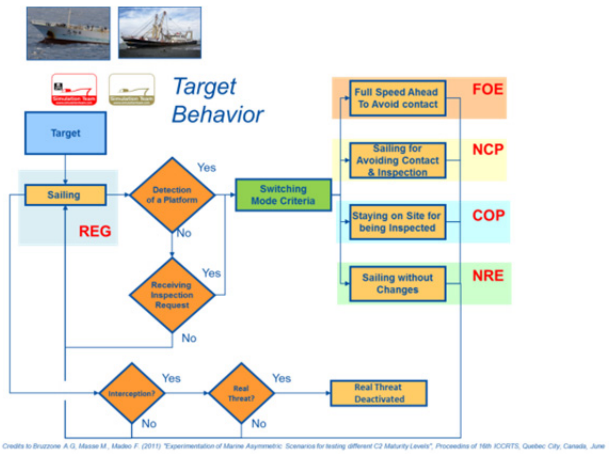


**Figure 5**: JAMS2 Targets Behavior

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 5).
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 1.

## 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 directory; 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 1**: 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 | ( 1 NM, 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 | ( 1 NM, 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 | ( 1 NM, 4 NM] | 20% | 15% | 50% | 10% | 5% |
| False Alarm | REG | >4 NM | 20% | 30% | 20% | 25% | 5% |

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

## 4 EXPERIMENTATION

Experimental campaign within the JAMS2 project addresses VV&A of the simulator. Due to the strong non linearities 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 paper it is proposed a part of the 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.

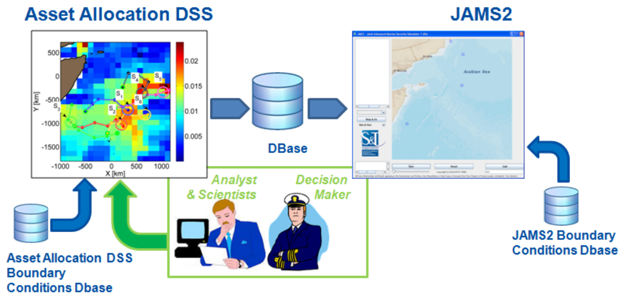


**Figure 6**: JAMS2 Original Configuration with Optimal Asset Allocator

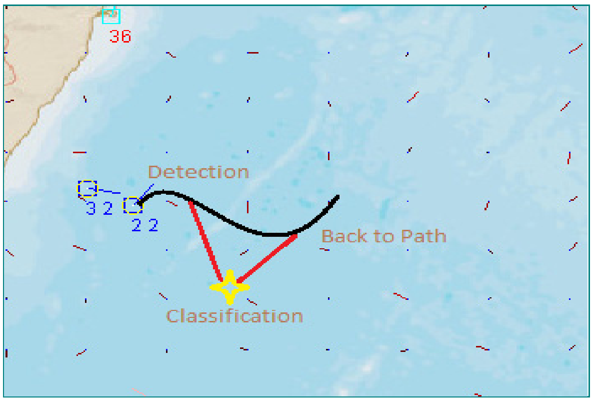


**Figure 7**: Asset Deviating from the Planned Path

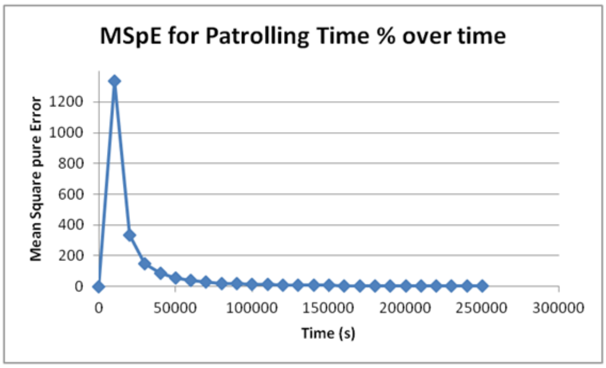


**Figure 8**: MSpE for Patrolling Time Percentage over time for Detection Range R1

In Figure 7 it proposed the graphical representation of the 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).
For each of the three cases the experimentation was conducted with the same number of replication using the same boundary conditions. The simulation duration is set to three days for each run; JAMS results over 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.

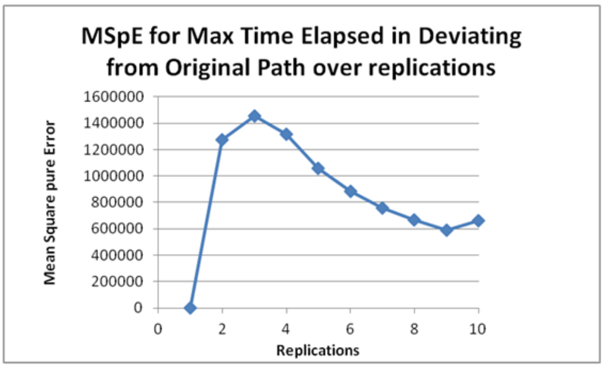


**Figure 9**: MSpE for Max Time Elapsed in Deviating from Original Path over replications for detection range R1

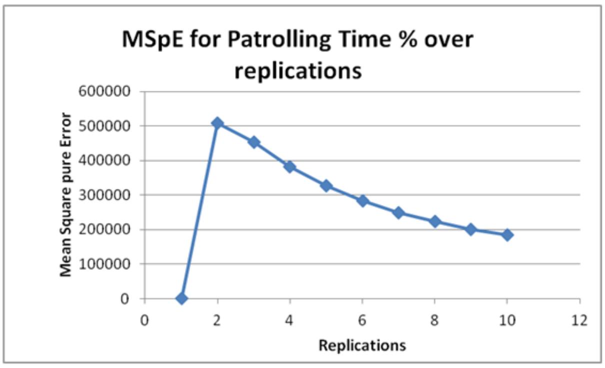


**Figure 10**: MSpE for Patrolling Time Percentage over replications for Detection Range R1

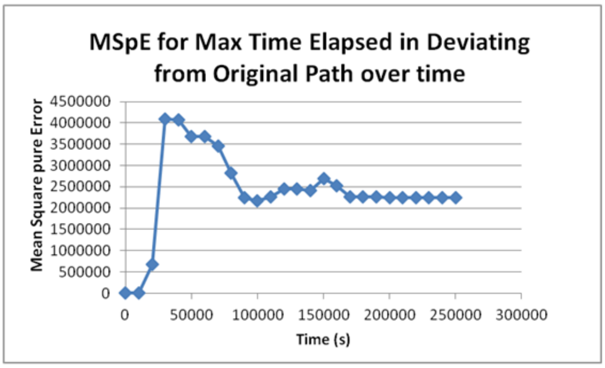


**Figure 11**: MSpE for Max Time Elapsed in Deviating from Original Path over time for detection range R2

Figure 11 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 15 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 17. Today the current release of the JAMS2 simulator does not include detailed models for sensors, weapon systems and communication due to resource constraints. Meta-models already implemented in JAMS2 guarantee the generalization capacity leaving space for future 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).

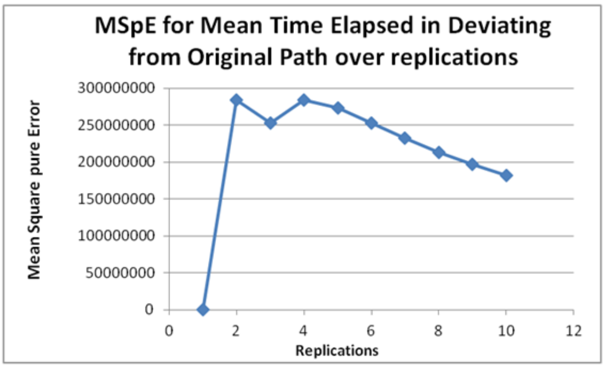


**Figure 12**: MSpE for Mean Time Elapsed in Deviating from Original Path over replications for detection range R3

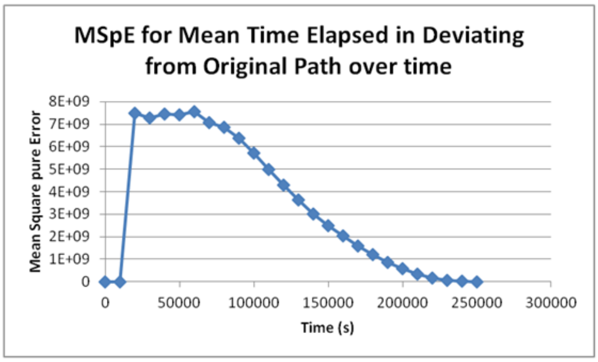


**Figure 13**: MSpE for Mean Time Elapsed in Deviating from Original Path over time for detection range R1

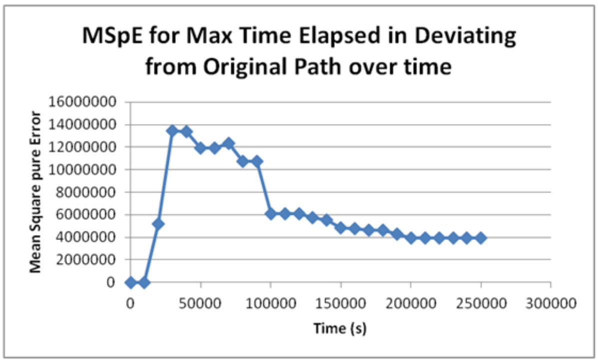


**Figure 14**: MSpE for Max Time Elapsed in Deviating from Original Path over time for detection range R3

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. The solution is good for current purposes, but it does not allow for the evaluation of the resilience of alerts generated by analyzing the RPM such as the deviating course of a boat toward a cargo ship (corresponding to generating suspects on its behavior); these kind of behavioral data fusion are currently somewhat limited in this case contrary to simulators such as PANOPEA and it could be possible to consider the extension of the current model.

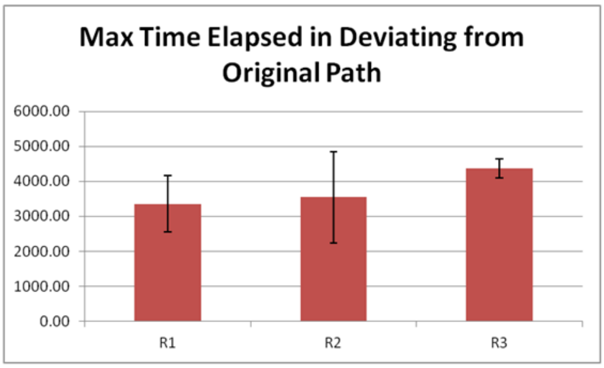


**Figure 15**: Average Max Time Elapsed in Deviating from Original Path over Intervention Range

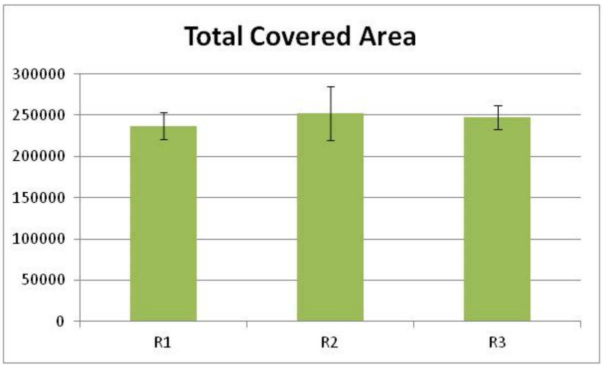


**Figure 16**: Average Total Covered Area over Intervention Range

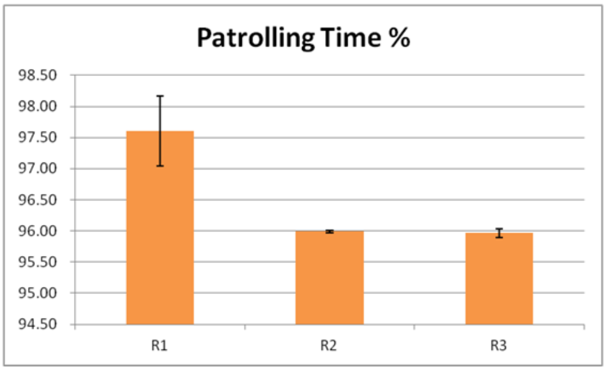


**Figure 17**: Average Patrolling Time Percentage over Intervention Range

In addition, thanks to the versatility of the JAMS2 architecture new type of assets could be implemented 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; therefore the authors are evaluating the possibility to investigate the adoption of 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 18

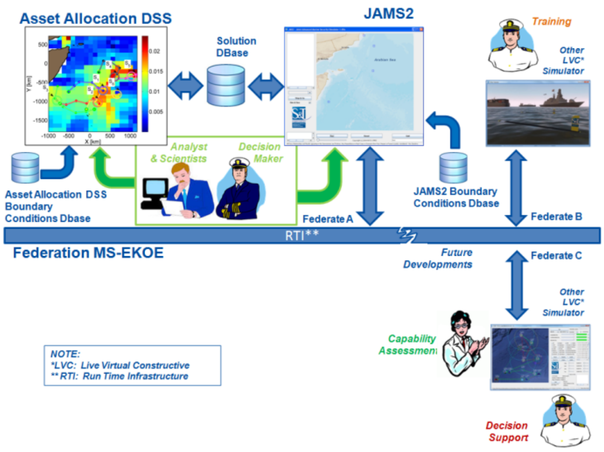


**Figure 18**: Example of a Federation with JAMS2

## CONCLUSIONS

This paper 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 authors suggest 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

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