A STRATEGIC SERIOUS GAME ADDRESSING SYSTEM OF SYSTEMS ENGINEERING

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ABSTRACT
Serious Games are currently extending their capabilities to strategic Education and Training by innovative approaches and new technological solutions. In this paper, the authors propose a new Serious Game devoted to address such aspects with special focus on System of Systems Engineering (SoSE). The proposed case uses a challenging framework related to the development of an innovative System of Systems for defense and homeland security that could be used by users to acquire the fundamental concepts of SoSE. The scenario allows to investigate alternative interoperable solutions among different platforms, sensors, infrastructures and doctrines respect evolving threats in relation to an air defense solution based on airborne radars.

Keywords: Serious Game, System of System Engineering, Stochastic Simulation, Web Applications, Homeland Security, Airborne Radar

INTRODUCTION

System of Systems Engineering (SoSE) represents a complex sector addressing the development of new solutions that overpass the complexity of the single system to become a common approach created by a really integrated and interactive approach to a challenging problem.
In facts, it is mostly impossible to create labs or exercises on SoSE without using M&S, so the authors decided to proceed by applying MS2G paradigm (Modeling, interoperable Simulation and Serious Game) to prepare a serious game devoted to Education and Training (E&T).
The proposed case study is quite challenging and the use of the simulation engine allows the students to test directly the concepts on a virtual project observing the effectiveness of different techniques and also the need to act in coordinated way with different project stakeholders. The proposed Serious Game, by its simulation engine, allows to estimate the impact of engineering and operational alternatives in terms of effectiveness and efficiency on the overall mission environment.
The authors have already conducted some tests with classes of industrial and academic students and are proceeding to further develop the simulator to be used for this purpose.

2 EDUCATION ON STRATEGIES RELATED TO SoSE

SoSE is a interdisciplinary approach that is popular in reference to development of new large and complex SoS (System of Systems), with the main goal to support a performance evolution based on properly defined requirements able to guarantee empowerment of the overall capabilities (Sousa-Poza et al.2008). Indeed SoSE is quite popular in aerospace and defense, but is in use also for large plants and other kind of SoS such as a new Pool of Power Plants over a region and their grid (Giribone et al.1996; Jamshidi 2011). In these sectors usually the complexity is due to the high number of interactions among different systems and the relative requirements makes pretty difficult to finalize an effective design able to balance efficiency, effectiveness and flexibility, so SoSE represent an important concept (Keating et al. 2005). Indeed the original motivation for introducing SoSE was strongly related to the capability of identifying proper requirements and configurations since the early phase of the project and let them evolve consistently with scenario evolution along the new SoS project life cycle (Jamshidi 2008). Indeed SoS are used to be large and complex and their projects involve big quantities of money and significant durations, so it is crucial to support early design and engineering in order to succeed, especially considering that these phases are affected by the strongest impact on maximizing the SoS performance with lowest efforts (Rhodes et al. 2009).
However, considering the nature of large programs, it is evident that these projects usually involve multiple players cooperating with final users and, quite autonomously, developing, managing and finalizing engineering of their specific systems that are elements of one or more systems; from this point of view, it is necessary to develop an approach able to guarantee that these activities are coordinated without losing the overall picture of the SoS and its performance in a wide spectrum of boundary conditions (Keating et al.2003).

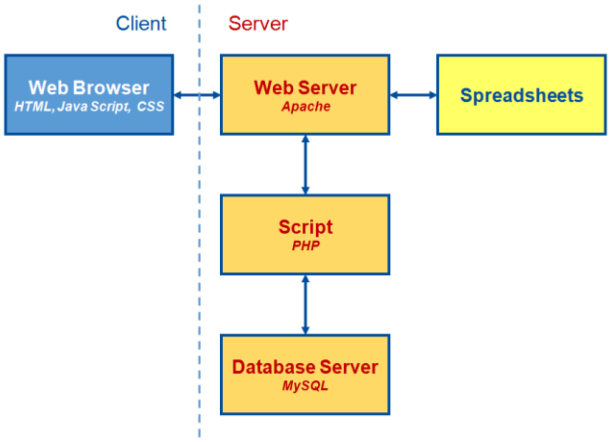

Figure 1 - MISCHIEF Architecture Client and Server

In general sense, the SoSE has to deal with many boundary conditions that affect the scenario including among the others: technical elements & engineering, operational issues, regulations and laws, finance, politics, social aspects, organizational factors; for instance considering the multiple players involved in these projects usually it is crucial to be able to couple the different perspectives of the stakeholders as well as their mutual relationships.
So, it necessary to support the objective and requirement changes along the project life cycle, not only in terms of engineering, but also considering functional and operational needs. In this way it becomes possible to dynamically adapt to the evolving functional requirements and capabilities of the overall SoS. Due to these reasons it is evident the fundamental role of Modeling and Simulation to support this approach and SoSE have been applied to several cases by the author with special attention to defense and aerospace sector, but also operating in industrial plants (Giribone et al.. 1996; Bruzzone & Bocca 2008).

3 SERIOUS GAMES AND STRATEGIC EDUCATION AND TRAINING FOR SoSE

SoSE as emerging approach for complex SoS is pretty interesting, therefore it is often not easy to transfer the capability to apply these concepts moving from a *generic declarative call for improvements* to an *effective renewed engineering approach*. In facts, in SoSE one of the crucial word is "Engineering": *why we need Engineering in SoS? Because these are very Engineering Intensive Systems… and their Combination is very complex… requiring a lot of Ingenium to illuminate us on understanding and designing the SoS (Bruzzone & Maglione 2016).* Due to the above mentioned reasons, it is evident the importance to develop capabilities in understanding and applying SoSE. The authors decided that in order to succeed in this direction it is necessary to create virtual frameworks devote to provide a direct SoSE experience to trainees. It should be outlined that the training audience for these techniques is pretty articulated including young engineers as well as project engineers, program managers, company executives, public authority managers as well as other stakeholders (Ncube 2011). Some of these individuals have very limited time and in any case the complexity of a real case related to SoSE could make almost impossible to experience it within a class, even if virtual, due to the number of details to be acquired before to get the whole picture.
In facts, Modeling and Simulation represents a great opportunity for SoS Engineering considering that:

- Physical experiments are typically infeasible in SoSE
  - Computer simulation is required to reproduce this context
  - Computer Simulation are expected to be quite computationally intensive and time consuming to address SoSE
  - Verification and Validation is challenging due to the high number of objects and variables
- SoS are complex
  - Special models are required to address each element
  - Many subsystems and variables to be considered also by meta-models
- SoS have a broad and articulated configuration space
  - Very large number of alternative configurations
  - Need to speed up simulation for extensive experimentation and data farming
  - Results could be hard to be understood, visualized and shared among stakeholders
- SoS have very high stochastic components
  - For a given set of inputs, it is required to define the uncertainty and their expected distribution in real operations to be simulated
  - It is required to adopt ANOVA and confidence band analysis for determine the output data distributions
- SoS include Intelligence as element for interoperability among different systems
  - It is required to include behavioral models
  - Behavior models should be modular to be able to combined under different conditions

In facts, M&S should be adopted taking into considerations these challenges and using consolidated methodologies (Amico et al. 2000; Mongomery 2000; Mittal et al. 2008). The state of the art review clearly reveals the potentials of M&S (in different domains) to come up with solutions able to take into account many of the issues mentioned above; from this point of view different review articles and specific applications can be found in Harvey and Stanton (2014), Davis et al., (2016); Longo et al. (2015).
Due to these reasons, the authors decided to develop an ad hoc scenario that provides a real challenge in terms of SoS and that is suitable for applying SoSE in short time, by an interactive and intuitive simulation environments to play with. The authors propose a strategic, dynamic stochastic simulation based serious game to be used during classes enabling fast time and distributed simulation; indeed by this approach it becomes possible to train people in different sites and

providing them interactive experience with other players over the web. The Serious Game could be designed to operate as web service in order to be usable in physical and virtual distributed classes from pc, laptop or even smartphone (Keegam 2005; Bruzzone et al.2014a).

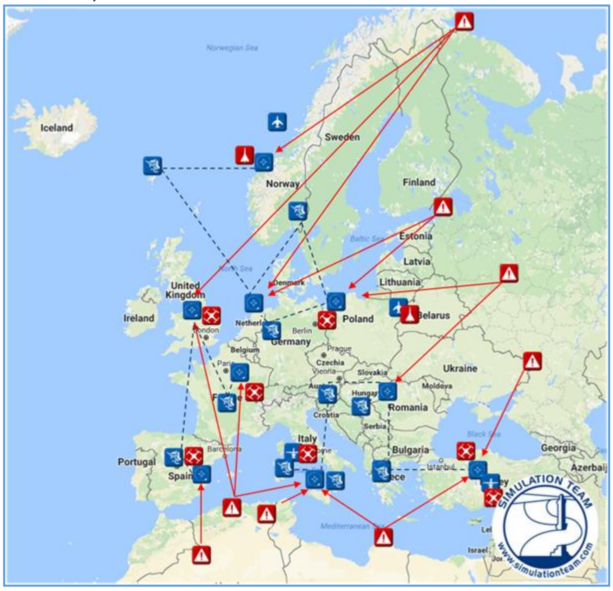

Figure 2 - MISCHIEF Scenario, Objects & Threats

The use of MS2G approach provide additional benefits by supporting interoperability and distributed simulation, so in this case the proposed solution adopt this paradigm (Bruzzone et al., 2014b) and it is named MISCHIEF (Multiple Interoperable Systems for joint Control of Hybrid threats through Intelligent Extended Fusion). The distributed use of MISCHIEF is guaranteed by the general client server architecture summarized in figure 1. Indeed MISCHIEF has been successfully experimented with industrial and academic users and deals with defense and homeland security respect air threats (Bruzzone and Maglione, 2016).

4 STRATEGIC SERIOUS GAMING

The proposed context deals usually with distributed operations respect a very broad spectrum of solicitations; so it is required that the players of the Serious Game should develop solutions with high level of interoperability ready to face all the potential challenges. Obviously another big challenge is represented by the uncertainty about the new different system real performance as well as on the real detailed characteristics of the scenario to be investigated. In facts in these very complex problems usually the real mission environment is not really well know and the design of new solutions relies strongly on hypotheses and assumptions; this image of the real mission environment, as it is supposed by developers, matches with “Simuland” concept proposed by McLeod. Indeed it is fundamental, while playing with the SoSE scenario, to check the consistency of the initial assumptions and hypothesis respect the emerging new information and knowledge (McLeod 1968; Amico et al.2000).
Obviously the SoSE should be applied by players keeping clear in mind the multi-target goals addressing operational performance, reliability and cost effectiveness (Bruzzone et al.2006). In this way the trainee, by acting as players in the MISCHIEF Serious Game, experiences interactively that fundamentals decisions, strongly affecting costs, are taken during the Early Phase of Project and learn how to proceed properly in system design during architecture definition. MISCHIEF goal is not only training, but also educating users on Capability Oriented Design, evaluating both the acquisition of additional capabilities as well as in an effective interoperability enhancing the overall capabilities rather than the single system performance, as suggested by SoSE in order to be able to address the diverse challenge (Bruzzone & Maglione 2016).

5 MISCHIEF CONTEXT BACKGROUND SCENARIO

The MISCHIEF scenario is related to defense and homeland security with special attention to aerial threats (see figure 2), so it address a complex SoS that involves ground installations, electronic systems, power engineering, multiple platforms, operational modes, etc.
The system is inspired by a real context addressing air space defense based on airborne radars; indeed from the end of the first half of XX century radars have been widely used in aerospace control in both civil and military fields. Depending on purpose they can be installed on fixed basement or mobile carrier such as truck, ship or plane. For example in civil air-traffic control typically used ground based radars are installed over tall infrastructures and towers (Nolan 2010).
However, the ground based radars have several limitations caused by curvature of the Earth and obstacles, such as trees, wind turbines and/or heels, create radar shadows hence limiting their capability to detect targets. This constraint was known since the beginning of World War II and was widely used by German aviation to reduce efficiency of British early warning radar system called Chain Home (CH) approaching to the coastline at low altitude (Brown, 1999). The only efficient solutions was installing as many radars as high as possible from the ground to reduce the radar's dead zones. Indeed thanks to the advances in electronics, soon new solutions were found installing the radar directly over special airplane devoted to carry out such task as in the case of AWACS (Airborne Warning and Control Systems) implemented over a large number of fixed wing airplanes (e.g. A-50, E-1, E-2C, E-3 Sentry, KJ-500, KJ-2000, PB-1W, , Tu-126 Moss) and also on helicopters (EH-101A, KA-31, SH-3H, Sea King AEW) and blimps (Good Year ZPG-2, ZPG-3).
In this sense, a very efficient solution is the installation of the sensors on flying platforms and today the autonomous systems are providing additional

opportunities in this field to add to planes also unmanned aerial vehicle (UAV) or unmanned LTAV (Lighter Than Air Vehicle). Nowadays it's impossible to imagine zone of military conflict or even movement of modern military forces without UAV, Airborne Warning and Control System (AWACS) or another reliable surveillance instrument with high mobility (Dorn, 2014). Even more, in many cases small targets, such as UAV themselves, flying at low altitude, are almost undetectable from the ground and the only reliable solution is based on airborne radars.

Obviously such systems are also used in civil fields, for example ground-penetrating radars (GPR) installed on UAV or helicopters are used in cartography of floods (National Research Council, 2004).

For any of mentioned above application simulation could be effectively used to support decision making as well as for training. For example, nowadays in air-traffic control simulators are used to support flow management (Tumer and Agogino, 2007; Shah et al. 2005), risk assessment (Stroeve et al., 2009) and even estimate airspace capacity (Majumdar and Polak, 2001).

In general, one of main tasks of defense systems is to detect and prevent airspace violation by civil and military flying objects; it should be said that in many cases, military flying objects are airborne surveillance systems performing gathering of information including capabilities of defense systems.

As mentioned above airborne surveillance systems are key components of defense and information support, hence are widely used in zones of military conflicts or during movement of military forces such as carrier strike groups (CSG), therefore current scenarios involving asymmetric threats and hybrid warfare introduce many more insidious menaces (e.g. drones) that require innovative defensive solutions.

However, airborne surveillance systems have some limitations, for example in terms of autonomy and patrolling time due to engine consumption and maximum carried fuel amount.

This means that engineering solutions should be strongly connected with the policies for using these assets and with efficient planning of operations; this represent a perfect example of System of Systems and the development of a breakthrough solution by introducing new enabling technologies such as UAV and other platforms and sensors represent a great case for a case study on SoSE. Due to these reasons the proposal for a new hypothetical airborne surveillance systems is the basis of the MISCHIEF serious game; in facts, as anticipated, the aim of this research is to develop an innovative tool for education and training to be used for experimenting it within SoSE and to explore the capabilities of new simulation solutions to find best configuration and support proper strategic decision making in this field.

6 MISCHIEF SIMULATION SOLUTION

Simulator contains several databases: targets (e.g. type, maximum speed and range etc), sensors (e.g. max range, mass, power consumption, MTTR, MTBF etc), generators (e.g. power, space, weight), mobile platforms on which sensors are installed (e.g. max duration of flight, max mass of load, costs etc.), ground installations at which platforms are assigned to (e.g. coordinates, capabilities), areas of origin of targets (e.g. coordinates, probability of departure, number of false alarms, etc.).

Table I– Example of Game Data Set on Radar Equipment

Radar Name	Range Max [km]	Acq.Cost [MEuro/year]	Op.Cost [MEuro/year]	Resolution [m2]	Detection Reliability	MTBF [h]	MTTR [h]	Weight [tons]	Volume [m3]
RDK1	500	100	25	1.00	95.0%	592.00	48.00	48.000	30.000
RDK2	100	10	2	1.00	94.0%	552.00	48.00	48.000	20.000
RDK3	100	10	3	1.00	93.0%	516.71	48.00	28.000	1.000
RDK4	50	2	0.5	1.00	94.0%	276.00	24.00	1.000	0.500
RDK5	120	25	7.5	0.25	98.0%	180.57	48.00	16.000	0.500
RDK6	50	16	4	0.50	96.0%	352.00	48.00	22.000	0.500
RDK7	100	14	2.8	10.00	80.0%	204.57	24.00	6.000	0.800
RDK8	40	4	1.6	5.00	88.0%	318.86	24.00	1.000	0.200
RDK9	35	2	0.4	0.20	97.0%	133.13	48.00	0.500	0.250
RDK10	60	0.5	0.125	7.00	84.0%	251.41	24.00	0.500	0.250

It is important to outline the need to develop an easy playable Serious Game: both GUI and scenario generators have to be designed to minimize the efforts of the users and to automate as much as possible the operations: MISCHIEF self generates the scenario based on reference data stochastically changing in terms of threats, system performance, etc. In this way multiple games could be easily set up in a quick and effective way. Another important aspect is that even just the simple definition of the disposal of assets and their initial conditions to finalize a configuration could be quite explosive in terms of decisions to be taken, resulting time consuming and characterized by low added value for trainees in terms of E&T in SoSE. Due to these reasons at the beginning of the simulation, after players have chosen sensors, platforms and other main systems, as well as their initial locations, the IA (Intelligent Agents) driving the different assets are self organizing their planning in a basic yet consistent way, in order to make the scenario immediately playable. The Sensors and platform should be chosen considering their cost, volume, mass, power consumption and other parameters, and the fine tuning of the engineering solutions is easily defined by players through MISCHIEF GUI. The Serious Game includes preliminary checks about the consistency of the configuration, in order to ensure a feasible combinations of sensors, generators, platforms and ground stations. For example if a platform have a payload exceeding its capabilities in terms of weight or volume, the Serious Game downsizes this configuration dismissing some equipment and consequently downsizing the system capabilities. This actions generate alerts that enable the trainees to identify and correct rising issues . When all mentioned above criteria are satisfied, simulation is initiated and experimental results are collected to further improve the SoSE. In facts, as soon as a configuration is tested by the simulation, more correct estimations respect the *a priori* performance value are provided to the player. In this way they have the possibility to review and adapt the engineering in order

to fill up the gaps. Each change made by the players is characterized by a project development cost that increase along the project timeline and it is computed as a mix of fixed elements and comparative difference respect previous configuration, in order to provide the feeling of the experimentation and prototyping costs. Targets and threats are placed in predefined zone and IA drive them based on behavioral algorithms; also in this case new sources and new capabilities and penetration strategies could be introduced along the game to check the resilience of the proposed SoSE and the capabilities of the players to adapt the solution to the emerging new challenges.
As anticipate MISCHIEF is implemented as a web service, with the simulator running on the Server even to avoid possibility for trainee to cheat on their client side (see figure 2). MISCHIEF is based on a connection the specific game Database generated to create the scenario at the beginning of the Game based on PHP and related server-side scripting, while it is used Apache Web Server to manage the client/server communication through HTTP (Hypertext Transfer Protocol) and/or HTTPS (HyperText Transfer Protocol over Secure Socket Layer),.
The architecture is based on a MISCHIEF client implemented in JavaScript using jQuery additional libraries executed within the web browsers and HTM HTML and CSS for GUI definition; this approach allows to operate as platform independent application and to be usable even from smartphones for mobile training. The simulation provide also dynamic graphics of the scenario evolution to simplify the problem understanding by using web-socket server; indeed this solution overpass the limitation of most browsers allowing to guarantee continuous update of the tactical situations and of the overall strategic variable. The MISCHIEF simulation engine is implemented by using Python, Autobahn and Twisted networking engine.
This solution have a big potential being able to support communications mostly in real-time and in the future it could be possible to proceed with further developments for operational use instead than just E&T.
MISCHIEF target function are measured through analysis of simulation results for the whole SoS:

$$Tre = t_x / \frac{1}{2} \cdot \left[1 + \frac{2}{\sqrt{\pi}} \int_0^{\frac{t_x - mtre}{\sqrt{2} \cdot stre}} e^{\frac{-t}{2}} dt \right] \leq \lambda$$

$$mtre = \sum_{i=1}^{m} \frac{t_i}{i}$$

$$stre = \sqrt{\frac{1}{m-1} \sum_{i=1}^{m} (t_i - mtre)^2}$$

Tre	Responsiveness
t_x	Reference time required to detect, classify and engage a target in the simulation
mtre	Mean time to classify and engage targets
stre	Standard deviation to classify and engage targets
m	Number of generated targets
λ	Threshold level for responsiveness (e.g. 80%)

The MISCHIEF Game could be played in standalone mode as well as in teams cooperating to find a best solution while they compete with other teams.
The authors are currently using MISCHIEF with different classes achieving very interesting results and being able to validate and verify the game rules and logic.

7 CONCLUSION

This paper present an early stage development of a new generation solution for addressing the challenging topic of Education and Training for engineers and decision makers engaged in SoSE. In facts, the SoSE is a pretty challenging environment and the preliminary results achieved through experiments with students as well as during professional courses for industry are pretty promising. Currently the authors are working to organize distributed exercises mixing different classes in order to evaluate the specific characteristics of players with different technical and cultural background respect the SoSE concepts.

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