Strategic Engineering as Closed Loop Approach to Address Complex Systems

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Abstract— **The innovative discipline defined as Strategic Engineering develops architectures dealing with Decision Making in Complex Systems. The paper proposes how to create a closed loop that combines Modeling & Simulation (M&S), Data Analytics and Artificial Intelligence (AI) to filter and elaborate Big Data, extract information, forecast impacts of decisions by Simulation and collect back the actual results to correct the models. In this sense, even the development and implementation processes should rely on special scientists and engineers able to address the complex problems by solid foundations in M&S and AI. Several real cases are proposed in the paper as example to show the potential of this approach and to validate the methodology.**

Keywords- Strategic Engineering; Modeling; Simulation; Artificial Intelligence; Data Analytics; Strategic Management,; Strategic Planning; Decision Making.

I. INTRODUCTION

Since many years, the Decision Makers have to address complex problems with many different factors and strongly correlated where there is just a limited number of degrees of freedom available to them and where the quality of the decisions are related to multiple opposite target functions [1][2]. Nowadays this situation is even more critical due to several factors including globalization, increased speed and dynamics of Businesses and International Affairs, New Players and more Interconnected world [3].

Indeed, looking around over the world, from Geo Politics to Business, from logistics to marketing, it emerges that these kinds of problems are turning very common and challenging, while the environment turn to be more and more time sensitive [4][5][6][7][8][9]. The second effects of the decisions as well as the high level of interconnectivity makes it hard to evaluate all consequences and it emerge the necessity to rely on a solid and strong methodological approach based on quantitative techniques [10]. From this point of view, a new emerging discipline, named "Strategic Engineering", represents a step forward able to use the state of art of current technologies to address Strategic Decision Making into an innovative way.

This paper proposes the foundations of Strategic Engineering as well as case studies where it could be effectively used to provide a strategic advantage in decision making; in addition the paper highlights that the approach should be part of a structured advance in the field of decision making that include educational programs and initiatives for young scientist and engineers as well as for executives and managers. The presentation of STRATEGOS, the 1st Master of Science in Strategic Engineering in Italy and among first ones in the world, represents an important initiative that provides new capabilities to this context, developed in strong connection with major International Institutions as well as multinational companies.

II. THE INNOVATIVE APPROACH LOOKING TO RELIABLE TECHNIQUES IN A NEW WAY

Nowadays, in reference to complex problems, it is quite popular to quote the sentence that "Explanations exist; they have existed for all time; there is always a well-known solution to every human problem — neat, plausible, and wrong" Mencken [11]; without disrespect for this journalist, turning popular after 1 century, the authors have a different point of view, we feel that this popularity emerges due to the simplistic approach of current politicians while complex problems could have many different solutions: elegant solutions, simple solutions, complex solutions as well as no solutions [10]. Thinking back to 66 million years ago, during Cretaceous–Paleogene boundary, the impact of an "asteroid" creating the Chicxulub crater, 150km radius and 20km deep, had a huge impact on the Earth climate: this was a problem that at that time (probably even nowadays) has no solution at least for the living animals over the planet [12]. Moving forward at IV century BC, the Gordian Knot appeared impossible to be untied, therefore Plutarch states that Alexander solved it simply by a single stroke of his sword.

In any case, simple or complex solutions are not always easy to implement and/or to identify; for sure to find them and to identify right decisions to deal with them is fundamental to acquire data, develop knowledge and understanding, evaluate consequence and to apply the solutions while keeping control of the situation to correct it

and achieve desired results. This paper keeps out of generic discussions and provides a description of how Strategic Engineering applies modern techniques to face these challenges. Strategic Engineering is a combined use of Modeling and Simulation (M&S), Artificial Intelligence (AI) and Data Analytics devoted to support Strategic Decision Making. Indeed modeling & simulation arisen since '50, to address especially rocket science and supersonic plane engineering, therefore industrial applications emerged within the same decade [13]; so this approach is still pretty advanced even today therefore its base dates back over ½ century. In similar way AI (Artificial Intelligence) origins are quite old and even Turing's developments emerged on '30 and '40 [14]. Data Analytics dates back even to much older times, being used in terms of "moving average" since Roman times to forecast demand of wines and other goods from worldwide.

Indeed, it is important to outline that these methodologies are consolidated, but their combined use is pretty innovative and could rely on new enabling technologies and conditions such as digitalization of companies, social networks, Internet of Things (IoT), Cloud Computing Capabilities, etc.

These methods have today additional capabilities not only for the advances in software, hardware, algorithms and methods, but also for the possibility to use them in closed loop, collecting effects of decisions from the reality and using as input in machine learning and self tuning components as proposed in Fig 1.

III. APPLYING STRATEGIC ENGINEERING

In the following the authors propose some case studies as example of the capabilities offered by applying Strategic Engineering

A. Threat Networks and Critical Infrastructure Protection

The Homeland Security issues represent pretty challenging environments, addressing multiple layers and risks related to strategic assets. In this sense, the Critical Infrastructures such as power grid, transportations, and data networks are assets that are targets to threat network and the development of new solutions to reduce their vulnerabilities. The solutions could be pretty wide in sense of approach: from technological solutions, usually as integrated systems, up to policies & doctrines as well as training and institution of ad hoc special teams. To develop these solutions it could be used also a wide spectrum of approach, from penetration tests (cyber or physical or combined), to training and table top exercise. Obviously to face these issues by a comprehensive approach it turns necessary to create synthetic worlds reproducing each different layer as well as their interactions to conduct virtual experiences and exercise [15]. Among these problems, a new popular issue is related to Hybrid Warfare that combines cyber & physical attacks, economics, diplomacy and International Relations with use of Strategic Communications (STRATCOM) and Information Operations (Info Ops) affect public opinion and force opponents to specific decisions [6][16][17].
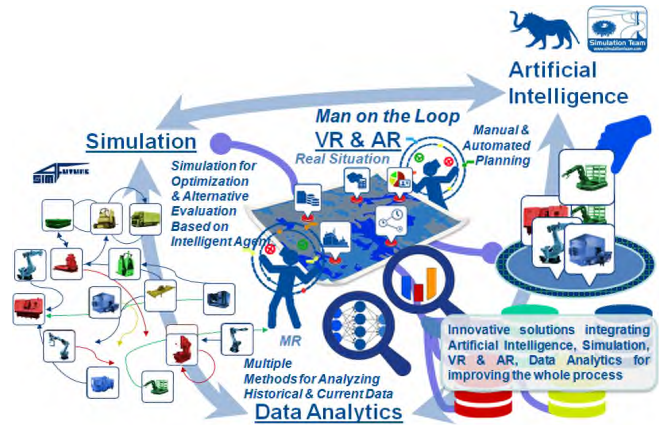

Figure 1. Closed loop use of AI, Simulation and Data Analytics to support decisions

In Hybrid Warfare the attack to critical infrastructures could represent an effective way to obtain results and influence population [18][19], so it is interesting to create models able to reproduce the behavior of people, the social media and collect information from the field to evaluate if the consequences of decisions are properly evaluated by the modes. At the same time, this approach could be used to refine the models and to introduce Machine Learning capabilities. The Solution named "Threat network simulation for Reactive eXperience" (T-REX) was developed in this way and demonstrated in 2015 the capability to reproduce cyber physical attacks by Unmanned Aerial Vehicles (UAV) to a Critical Infrastructure serving 5 towns over a desert area, including Tank Farm, Refinery, Oil Terminal, Port, Power Plant and Desalination Facility (see Fig 2); it is interesting to state that a similar attack was conducted against the biggest world refinery along 2019 in similar way [20].

B. System of Systems Engineering applied to AWACS

The renew of Airborne Warning and Control System (AWACS) is an actual issue that deals with the development of a new solutions to a complex problem that is still relying on old technologies on both West and East.

Up to now, big former commercial or transport planes have been adapted to carry large radar shaped as a mushroom (the radome) to discover on very long-range aerial and surface targets with good resolution as well as to support intensive and secure communications; classical examples are Boeing E-3C and Beriev A-50. Nowadays these solutions are very expensive, hard to maintain, to upgrade and operate. In addition, there are potential solutions, available today for instance based on use of autonomous vehicles that could reduce costs as well as vulnerability of the overall system through redundancy. New solutions could even increase coverage and responsiveness. In facts without human crew aircrafts could result lighter, more compact, reduce their consumptions and increase autonomy; obviously the new radar and communication technologies are now using different paradigms and could be more compact and integrated.
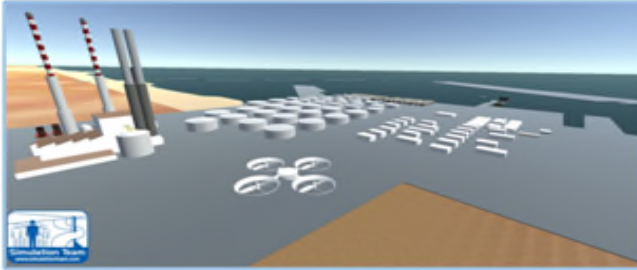
Figure 2. Vulnerability Reduction on Critical Infrastructures by using Strategic Engineering and Simulation

Therefore to find a reliable solution in this sense requires to consider many aspects such as the threats and the future scenario to face, the costs and reliability issues, the technological aspects on the platform, the technological aspects on radar solution, the operational modes and strategies, etc.

Even Key Performance Indicators (KPIs) are including many different target functions that are often conflicting as the case of costs versus vulnerability; to properly find optimal solution the authors developed the "Multiple Interoperable Systems for joint Control of Hybrid threats through Intelligent Extended Fusion" (MISCHIEF) that is focusing on defense and homeland security with special attention to aerial threats and include a simple modeling of complex SoS (System of Systems); this solutions create a complex scenario and simulation models to be used for supporting table top exercises as well as engineering analysis considering electronic systems, power engineering, multiple platforms, operational modes as well as ground installations (e.g. airstrips and bases for the new AWACS).

MISCHIEF was developed by Simulation Team as a Serious Game based on Modeling, interoperable Simulation and Serious Game (MS2G) to be intuitive and immersive [21]. In this context, the different engineering solutions are strongly interconnected with the procedures adopted to employ these new assets. The case proposed is a good example on System of Systems Engineering (SoSE) and is available to support evaluation of new hypothetical airborne surveillance systems considering several data such as platform type, maximum speed, autonomy sensor ranges, resolution, power consumptions, reliability and availability, etc.

C. Improving Industrial Plants: Increasing Line Productivity, Reliability and Safety

In modern factories and production plants, the evolution related to Industry 4.0 paradigm is enabling new advances. The proposed case is related to the Project named "Wearable Augmented Reality for Employee safety in Manufacturing sYStems" (W-ARTEMYS) where use of Extended Reality (XR) combining Virtual and Augmented Reality (VR & AR) is able improve safety and productivity in plants. This project allows to provide wearable solutions that rely on simple tablets or smartphones as well as on headsets and Hololens[TM] [22]. Therefore this is just the basis to create Strategic Engineering supports that acquiring all the information provided naturally and intuitively by operators and supervisors along production line and correlating them by Machine Learning could provide the based to create Intelligent Solutions suggesting how to react to alerts and how to improve quality and productivity, maintaining very high level of reliability and safety. The project is applied to hollow glass production lines, but is ongoing in parallel with other related initiatives over beverage bottling lines and frozen good industries.

IV. STRATEGOS AS NECESSITY

It is evident that in addition to developing new models, algorithms and even more combining these elements as integrated closed loop solution for supporting decision making, it is necessary to develop engineers and scientists with a new forma mentis relying on Strategic Engineering approach. From this point of view around the world, several new initiatives are arising such as STRATEGOS in Genoa University [10]. STRATEGOS is a new Master of Science on Strategic Engineering organized in joint cooperation among different Faculties (Engineering, Economics, International Affairs), Institutions (e.g. NATO M&S Center of Excellence, James Cook University Singapore Campus) and Companies (e.g. Accenture, Hitachi, Leonardo, Thales, MBDA, Rina, Seastema, Antycip Simulation, SIM4Future, Rulex etc.). MSc STRATEGOS is a two year International Program [23] that is based on 3 semesters of Lectures, Exercises and Labs plus a Semester of Internship working on a Strategic Engineering Project. The Program is active since 2019 and it has been presented in Tucson, Logrono, Milan, Berlin, Rome, Singapore, Beijing, Wroclaw, Taranto to create an effective network on this subject. STRATEGOS, as new Educational Solution, addresses both young engineering preparation as well as executive and manager upgrades; indeed this is possible through the development of the STRATEGOS Courses side by side with STRATEGOS Workshops addressing specific topics and open to experts from Companies and Institutions. Up to now, STRATEGOS includes already over 70 Workshops and obtained very interesting results in terms of attendance and quality reports.

It is evident that the success in diffusing and applying Strategic Engineering relies on the capability to interact with Top Level Decision Makers, so the new engineers as well as the manager, should learn these approach as well as the capability to collect from the top the needs and expectations as well as to guarantee trustiness on new solutions and their effective use.

V. CONCLUSIONS

The Strategic Engineering is a new approach that emphasizes the combination of AI, M&S and Data Analytics in closed loop getting benefits from the digitalization of the modern world; in this way this approach results much more efficient than in any past similar tentative and allows to filter, elaborate Big Data as well as to guarantee a continuous evolution and tuning of developed models based on machine learning support. It is evident that this approach provides great opportunities in a wide spectrum of application and this

paper proposes different cases that support both Defense and Homeland Security as well as Industrial Plants and new complex System of Systems Engineering. It is currently emerging a big need to develop such applications and to encapsulate them within the Decision Making Processes, due to these reasons the development of Educational Programs for young engineers and scientists as well as Continuous Education for Executive and Managers is crucial for guarantee success. Future competitiveness is expected to strongly rely on the use of these innovative Solutions and in their integration with different systems and processes.

REFERENCES

[1] K.M. Eisenhardt and M.J. Zbaracki, "Strategic decision making". Strategic management journal, 13(S2) 1992, pp. 17-37.

[2] T.L. Saaty, "Decision making for leaders". IEEE Transactions on Systems, Man, and Cybernetics, 1985 (3), pp. 450-452.

[3] B. Wooldridge and B. Cowden, "Strategic decision-making in Business". In Oxford Research Encyclopedia of Business and Management, 2020.

[4] A.G. Bruzzone, M. Massei, A. Tremori, S. Poggi, L. Nicoletti and C. Baisini, "Simulation as enabling technologies for agile thinking: training and education aids for decision makers". International Journal of Simulation and Process Modelling 2014, 9, 9(1-2), pp.113-127.

[5] H. Garg, "Some methods for strategic decision - making problems with immediate probabilities in Pythagorean fuzzy environment" International Journal of Intelligent Systems, 33(4) 2018, pp. 687-712.

[6] V. Gerasimov, "The value of science is in the foresight: new challenges demand rethinking the forms and methods of carrying out combat operations ", Military Review, January-February 2016

[7] J.K. Levy, "Multiple criteria decision making and decision support systems for flood risk management". Stochastic Environmental Research and Risk Assessment, 19(6), 2005, pp. 438-447.

[8] A. Özdağoğlu, " A multi-criteria decision-making methodology on the selection of facility location: fuzzy ANP". The International Journal of Advanced Manufacturing Technology, 59(5-8), 787-803. 2012

[9] F. Xiao, "A novel multi-criteria decision making method for assessing health-care waste treatment technologies based on D numbers". Engineering Applications of Artificial Intelligence, 71, 2018, pp. 216-225.

[10] A.G. Bruzzone, "MS2G as pillar for developing strategic engineering as a new discipline for complex problem solving", Keynote Speech at the International Multidisciplinary Modelling & Simulation Multiconference, Budapest, September 2018

[11] H.L. Mencken, "The divine afflatus". New York Evening Mail (16 Nov 1917)

[12] P. Schulte, L. Alegret, I. Arenillas, J.A. Arz, P.J. Barton, P.R. Bown, T.J. Bralower, G.L. Christeson, P. Claeys, C.S. Cockell and G.S. Collins, "The Chicxulub asteroid impact and mass extinction at the Cretaceous-Paleogene boundary", Science 327, No 5970, 2010, pp. 1214–1218.

[13] J. McLeod and S. McLeod, "Simulation of the society", Simulation, 43(6), pp. 320-323

[14] A.M. Turing, "Intelligent machinery", Technical Report of National Physical Laboratory, UK, 1948

[15] A.G. Bruzzone and M. Massei, "Simulation-based military training", . In Guide to Simulation-Based Disciplines 2017, pp. 315-361. Springer, Cham.

[16] V. Gerasimov, "The value of science is in the foresight ", jounral Voyenno-Promysh-lennyy Kurier online , February 26, 2013, (original version in Russian)

[17] E. Cayirci, A.G. Bruzzone, F. Longo and H. Gunneriusson, "A model to describe hybrid conflict environments". Proc. of 13th International Multidisciplanary Modeling & Simulation Multiconference (I3M 2016), 26-28 September 2016, Larnaca, Cyprus (pp. 52-60)

[18] P. Di Bella, "Present and futures scenarios and challenges for M&S terms of human behavior modeling", Invited Speech at I3M2015, Bergeggi, Italy, September 2015

[19] A.G. Bruzzone, M. Massei, R. Di Matteo and I. Vianello, "Innovative modelling of social networks for reproducing complex scenarios", Proc. of I3M, Barcelona, Spain. September 2017.

[20] J. Defterios and V. Cavaliere, "Coordinated strikes knock out half of Saudi oil capacity, more than 5 million barrels a day", CNN Business, 1000 GMT, September 15, 2019

[21] A.G. Bruzzone, M. Massei, G.L. Maglione, K. Sinelshchikov and R. Di Matteo, "A strategic serious game addressing system of systems engineering", Proc. of MAS, Barcelona, September 2017, pp. 214-219.

[22] A.G. Bruzzone, M. Massei, K. Sinelshchikov, F. Longo, M. Agresta, L. Di Donato and C. Di Francesco, "Wearable mixed reality solutions for industrial plants and production lines", Proc. of the Int. Conference on Modeling and Applied Simulation 2019, pp. 181-185.

[23] www.itim.unige.it/strategos