BrainSim - Systems of Systems Engineering Simulation a New Approach – Final Report

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Abstract - **There is an increased interest in System of Systems (SoS). The availability and affordability of communication, computers and software made many systems to connect to each other and create networks with different stakeholders who collaborate to achieve common goals. There are many examples of SoS around us and they are part of our everyday life such as: Net Centric Warfare (NCW) System, transportation, electric grid, hotel chains, navigation, banking etc… are all Systems of Systems.**

Communication, computers and miniaturization are the key enablers which are driving the evolution of systems into SoS. Those technologies are accelerating the high connectivity between many types of systems, data bases, processes and stakeholders.

Medium and large systems integrators industries have a growing interest in SoS. As they are always trying to move upwards the value chain in order to maintain their survivability and growth. To maintain growth companies must seek for introducing new systems, capabilities or processes to the market. Today this innovation phase is done in the environment of SoS. Shumpeter claims that companies and even societies must innovate and introduce and design new systems in order to survive

System of Systems does not introduce only complexity but also introduce human interaction and behavior with systems in a network. This is because SoS is: *"A collection of interconnected human operated systems"*. There are many definitions in the literature for SoS[1] some of them do not contain the operators explicitly. We claim that a collection of systems which operates collectively by one operator can be analyzed as more complex system. We chose the above definition which introduce the human operator to each node in the network since represents modern networks systems such as: ground and air transportation systems, banking systems, communication systems etc…

SoS architecture and tools can assist to achieve high *interoperability* between organizations and individuals. Where an interoperability definition extended by Network Centric Operations Industry Consortium (NCOIC) to: “interoperability within and across domains can be best achieved when all dimensions -- technology, mission, business value, policies and regulations, and culture -- are considered and addressed”

One of the strong engineering tools is *simulation* however simulation of SoS is not developed enough yet since there is difficulties in embedding *human factors* and a *common language* between system’s’ stakeholders of SoS members.

[1] There are several definitions in the literature for System of Systems such as: Systems of systems exist when there is a presence of a majority of the following five characteristics: operational and managerial independence, geo-graphic distribution, emergent behavior, and evolutionary development (Jamshidi, 2005), Systems of systems are large-scale concurrent and distributed systems that are comprised of complex systems (Carlock and Fenton, 2001; Jamshidi, 2005), Enterprise system of systems engineering is focused on coupling traditional systems engineering activities with enterprise activities of strategic planning and investment analysis (Carlock and Fenton, 2001), System of systems integration is a method to pursue development, integration, interoperability, and optimization of systems to enhance performance in future battlefield scenarios (Pei, 2000), SoSE involves the integration of systems into systems of systems that ultimately contribute to evolution of the social infrastructure (Luskasik, 1998), In relation to joint war fighting, system of systems is concerned with interoperability and synergism of command, control, computers, communications, and information (C4I) and intelligence, surveillance, and reconnaissance (ISR) systems (Man thorpe, 1996), SoS are large-scale integrated systems that are heterogeneous and independently operable on their own , but are networked together for a common goal (Jamshidi, 2009).

In this paper we will present an innovative new method approach of SoS simulation. This new approach is bases on adding to SoS simulation:

a. **Simulating stakeholders' behavior.**
b. **Common language and mediation mechanism between systems' stakeholders.**

We will describe a process how simulate stakeholders' behavior which will be done by identifying response of N400 to a new information.

I. From systems to system of system – the birth of SoS

In the last decades there is an increased interest in System of Systems (SoS). Availability of communication and computers made it easy for systems to be connected. The demand for interoperability of systems, stakeholders and organizations to achieve new collective goals became important. SoS is formed of a cluster of different systems connected between them with independent stakeholders. There are many definitions in the literature of SoS, we will coin the following definition: **"A collection of interconnected human operated systems".** The major characteristic of SoS is that each System is human operated and free to make independent decisions. According to the above definition SoS is born out of more than two operators who communicate and decide together to collaborate to achieve a common goal.
Moreover in many SoS there are stakeholders who are not operating the individual systems however they have an influence on the individual operator and the behavior of the whole SoS. For example the legislator in each country defines traffic rules and fines and by that effects drivers' decisions on roads. Those stakeholders can be individuals or group entities such as: municipalities, countries, unions etc…which has interests and generate rules for the population in the network.

Systems are very predictable even if they are human operated since we design them to follow exact embedded performance. Even adding complexity to a single system will not change its predictability to a given disturbance. One of the most powerful tools of Systems Engineering is simulation which enables us to predict the system's behavior to different stimuli.
However in SoS there is an interaction between the systems where one system human operator decision can affect the response of the other systems' human operator decisions. For example if four aircrafts flying in a formation and one of the pilots decides suddenly to take an individual course the other three pilots decision will be affected and they can decide to fly without him or to join him. Another example could be when one driver on a highway saw a pedestrian crosses the highway and decides to slow down other drivers behind him who can not see the person crossing can decide to slow down or to bypass him and danger him. Either reaction of the other drivers can cause a chain effect on the highway.

There is no pre predicted algorithm to estimate the response of each operator/ stakeholder response connected to the network. This means that we cannot predict the SoS overall behavior. SoS is not only about a larger complexity scale compared to each System by itself. There are many systems which are very complex however SoS introduce new dimension of complexity which derived from the human interaction in the network. Unlike Systems which are designed to perform a definite pre planned behavior a SoS has a goal or several goals to achieve and since it depends on human behavior it introduces an additional type of complexity which is difficult to predict.

III. The "glue layer"

Electronics miniaturization accelerated communication, computer science and engineering. Systems were connected to each other rapidly and constructed networks (Fig 1.). In most cases it was an evolving process. Transfer of information is done over a communication "cloud". Every system is driven by a different stakeholder which is a member in the network and affects other members' behavior and by that it is influence the goal to be achieved.

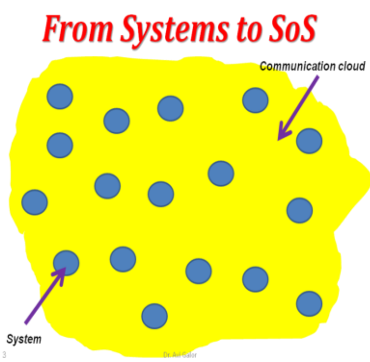

Fig. 1 - From System to SoS – the Network

Connectivity between systems in different networks evolved over the years and an Open System Interconnection (OSI) was introduced. Today it is common to describe OSI with a seven layer model depicted in Fig 2.

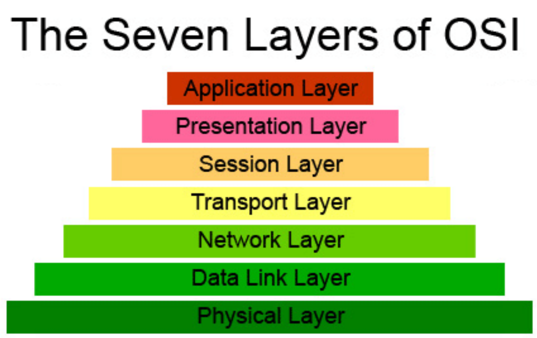

Fig. 2 - The Seven Layers model of OSI

SoS introduces an additional complexity due to the fact that they have different stakeholder and they evolved over time where new systems with their operators are connected to the network and with their unique standards. This means that there is no "common language" between them SoS members. The distributed nature of the network and storage technology improvements results also with a distributed data bases rather than stored in a central storage this fact also enabling different systems with their stakeholders to be connected and join the network independently. Data release policy to the network members is done by the individual stakeholders who introduce even more complexity. Network Centric Warfare (NCW) concept is an example of those difficulties. The need of the different forces within one nation to interconnect and maintain interoperability to achieve a common goal to achieve superiority arise the above complexities and difficulties. Moreover when interoperability is needed between coalition nations the difficulties of "no common language" even become bigger.

IV. Systems performance Vs. SoS Goal

Systems engineering is about analyzing and synthesis to achieve system's performance. The performance of a system is considered to be predictable and therefore we can in create an effective simulate one of the system. However since SoS contains operators and stakeholders they are not always predictable. Moreover since SoS contains human operators it is also about achieving Common Goal (CG) and a New Capability (NC) of collection of systems which are part or SoS. Note that that the CG and the NC is of the SoS and not of the individual system in the network.

A new goal or capability can be achieved only if part or all stakeholders will "play" together and collaborate. Collaboration is done by stakeholders and operators exchanging and sharing thoughts, knowledge, ideas and knowhow over the network via the “glue layer”

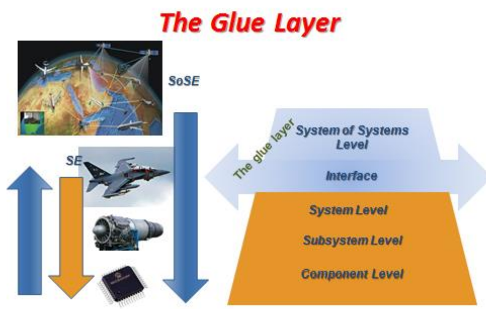

Fig. 3- The Glue Layer

The GL (Fig. 3) is about the interface between the stakeholders of its systems in a broader sense. The GL is where operators and stakeholders exchange not only information but also: ideas, policies, agreements and disagreements. Over the GL collaborations are created to achieve CG by collaborating between stakeholders and by competitions as well.

Fig 3 depicts on the left hand the notion of systems which are comprise bottom up from a component level towards a subsystem level to system level and with connectivity to other systems towards SoS level. Systems engineering and SoS Engineering deals with analyzing Systems and SoS top down process. On the right hand side there is the “hidden” layer which connects the systems which we call the “glue layer”.

V. SoS Simulation

One of the effective systems engineering tool is simulation. Although there is an ongoing attempts to develop SoS simulations such as interoperability simulations[10] SoS Engineering do not have yet effective simulation tool to asses new ideas impact on SoS in the ideation stage and even when we move to the feasibility stage we cannot predict the SoS behavior when we adding new system, assessing interoperability[4] level, policy change or achieving CG etc. In the military domain some are using Battle Lab’s in overcome those difficulties. A **battle lab[5]** or *battle laboratory* is a capability enabled by a set of means (premises, teams, operational equipment or operational platforms, hardware, software, IT infrastructure, processes, guidelines) to analyze or assess impacts that could be induced by changes in a military realm. The changes can be of any kind: equipment, technologies, organization, doctrine or changes in the environment itself[6]. However this tool is very costly and complicate to use. Using Battle Labs instead of simulation is mainly because of two major reasons:

a. Lack of common language and mediation mechanism between systems’ stakeholders
b. There is a need to simulate stakeholders’ behavior.

VI. Creating Common Language Between Systems’ Stakeholders

As mentioned before SoS differs from a system by connecting between different systems which are controlled by their stakeholders. Therefore their ability to convey ideas over the network is crucial. This is more than sending messages over communication channels of the network - it is about idea exchange like we do in free language between human beings. It is not about the data flows in the network it is about the content, the meaning of it and also interpretation of stakeholder's idea and meaning content. We suggest doing it with **semantic tools**[7]. Semantic tools[2] can deal with different data bases types (structured and unstructured) and ideas. Semantic tools provide mediation mechanism between stakeholders where: RDF (Resource Description Framework) is a common model representation, OWL (Ontology Web Language) which is using RDF, inference tools, and rule base engines. [3]This model is more appropriate for the distributed nature of a SoS where each stakeholder can use same basic algorithm to build his ontology map of the 'world' around him, make his own inference, take independent actions and convey data and ideas over the network to its members.

VII. Simulating stakeholders' behavior

Additional feature we have in SoS is that we need to predict the systems' operators and stakeholder behavior who are members of the network. Without doing it the simulation tools describe only the network topology, the individual systems and data exchange between systems in the network. However SoS is also about the response of its' operators and stakeholders to evolving situations in the network. This is more like trying to simulate social networks. SoS differs from mathematical models of static complex systems because at each node there is a human operator. One of the options is to use **intelligent agent technology** to describe the human like behavior of the operators and stakeholders who are member of the network. By human behavior we mean: "human reaction to information". By **human reaction to information** we mean that when the operator hear/see/sense new information it effects his reaction and he operates in a different way. For example while we are driving on a highway and we hear in the radio that there is traffic jam in the next segment we seek for a different route or we can decide to stop in the next rest area and drink a coffee. New information about storm broadcasted in weather forecast news affects if a pilot takes off and this can affect the international schedule of other flights etc.

Rather than using a synthetic Intelligent Agent or Smart Agent to represent stakeholder's reaction to information and ideas flows from its neighbors we suggest base the model on scientific – physical measuring (using EEG tools - which is presented in the N-400[8] events case in this paper). We are proposing to measure the brain N-400 response and simulate it[3]. Where N400 is part of the normal brain response to words and other meaningful (or potentially meaningful) stimuli. Including visual and auditory words, sign language signs, pictures, faces, environmental sounds, and smells[9].

The N400 event represents reaction of a Noiron (N400) to incongruence of a word to the context of a sentence. This event was revealed by Prof. Kutas in the seventies of the last century[4]. The N400 event was later generalized to pictures/video and voice. The experiments had been based on using E.E.G.
A known experiment had been held by presenting to a set of persons the sentence: "David likes to drink his coffee with sugar and milk". There was no reaction to the above sentence. Afterwards a new sentence was presented: "David likes to drink his coffee with sugar and his dog". To that sentence a reaction was defined by the E.E.G. . . . This was defined as the N400 event.

VIII. BrainSim assumptions and extermination stages

Our main assumption is: People are reacting to "information" especially to "new content" or to incongruent content.

A reaction can be a change of position, a physical action or just an update of his Mental Data Base (MDB).

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[3] At the second half of the 20^{th} century, many researches of unstructured texts analysis were conducted. The main assumption was that the basic structure of every language is the same, and extraction of the semantics of any sentence can be extracted by a computerized system. Extraction of the Subject – Verb – Object means – extraction of the sentence semantics. This can enable us to identify any person's positions using computerized text analysis.

The main course of this simulation is to build a process, which will define the linkage between external inputs of “information events”, and “position update/change” as function of those “running-in information event/particle”, or by many “information particles”.

For that we will conduct a lot of experiments that will be conducted by brain research researches and human examinees teams (as a standard scientific experiment in the field of consciousness research). For example we intend to use measurements of N-400 response - to external information .

Our main tools for creating the Mental Data-Base processes (which will be a data base of the network) will be a series of a three-step phase experiment: (Example of using the N-400 response).

Step one – presenting a new information-content to a set of examinees (50) and measuring their EEG reaction. If there will be an N-400 type reaction (for example) we will move to the second step .

Step two – using a Machine Learning text and other stimuli (such as: pictures, movies, audio) analysis for evaluating possible changes or updates of positions of those examinees. Out of the outcomes of the Machine Learning text analysis system we are going to build a Characterized Feature-Vectors (CFV). The CFV represents each examinee “positions” before he/she receives a new running-in information particle and will be updated when there is a change in the examinee’s positions.

The procedure of those above two steps will create many outcomes, which will construct a relevant data for machine/deep learning analysis. It means – for every “consciousness profile” (specific person) the machine learning will predict what will be its reaction as function of the information event. It means that at the end of this phase we will have a simulation of human operator reaction to external information.

Step three – a verification phase. We are going to compare the above simulated prediction to external information-reaction and compare it to the real reaction. This will be done by exposing the external information to a “real” individual and measure his/ her N400 response.

The process of the procedure described above is depicted in Fig. 4.

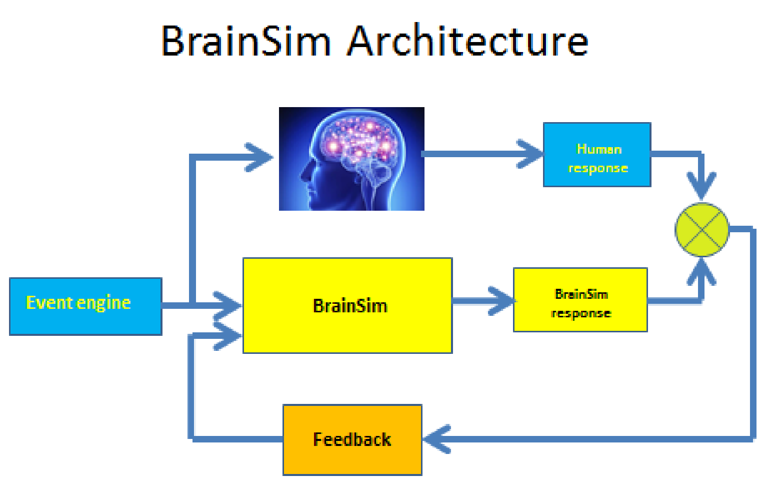

Fig. 4 – BrainSim architecture

Remarks – the procedure is adaptive – it means – we will update the experimental parameters as function of the outcomes, and, as a function of the need to filter many noisy factors. It means that there is a need to identify the noisy factors. We plan to do that by changing the groups of examinees.

Out of the above described process a data-base will be created. This data base will be used to extract the simulation outcomes. It means – for every individual BrainSim will evaluate change of the human operator position/ action to external information (for a specific and predefined issue) and will update his/her MDB.

When there will be no relevant history in the MDB, a Bayesian-dynamic model will be used. It means that for every individual (for the evaluation of his/her positions changes) whom his/her consciousness profile is not known yet we will produce this type of algorithm which will predict his/ her initial position/ action. This will be use also as a kind of a reinforcement algorithm.

In the second part of the research we will create a simulation of many individuals (human operators) connected via a network using semantic tools, and tries to simulate the "positions updates" of all of them as a "states machine". For this we will need to develop a common language between the human operators of the individual systems in the network. It means – the simulation will predict the New Goal of the SoS. This procedure is illustrated in Fig. 5 and Fig 6.

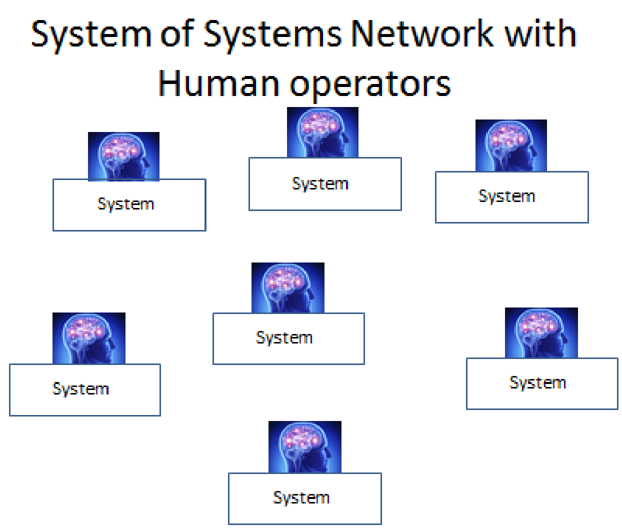

Fig. 5 – SoS Network with human operators

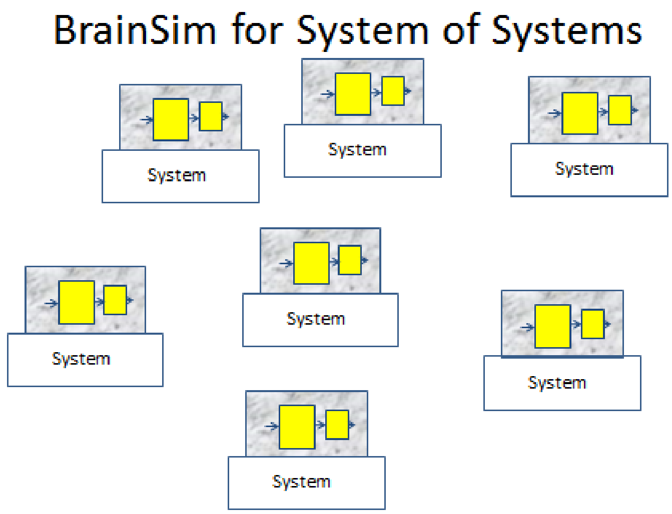

Fig 6. – BrainSim for SoS

IX. SUMMARY

SoS differs from Systems innovation by the fact there are two new dimensions: (a) stakeholders are part of it, (b) network as a medium for exchanging information and ideas between members. The Glue Layer was introduced where stakeholders exchange data and ideas between them which enable them to mediate and collaborate toward common goals (or compete).

Important enabler for SoS innovation are simulation tools. We presented a new approach of developing "common language" (between the SoS stakeholders) based on Semantic tools. Also as a first step we designed an experimentation method to simulate human behavior by measuring N-400 response.

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