A Case for an International Consortium on System-of-Systems Engineering

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***Abstract*—A system-of-systems (SoS) conceptualization is essential in resolving issues involving heterogeneous independently operable systems to achieve a unique purpose. Successful operation as an SoS requires communication among appropriate individuals and groups across enterprises through an effective protocol. This paper presents a position on the creation of a consortium of concerned system engineers and scientists worldwide to examine the problems and solutions strategies associated with SoS. The consortium could lead efforts in clarifying ambiguities and in seeking remedies to numerous open questions with respect to SoS analysis, SoS engineering (SoSE), as well as differences between systems engineering (SE) and SoSE. The mission of this consortium is envisioned to: 1) act as a neutral party; 2) provide a forum to put forth Calls to Action; and 3) establish a community of interest to recommend a set of solutions.**

***Index Terms*—Academia, consortium, government, IEEE, INCOSE, industry, military, system-of-systems (SoS).**

I. Introduction

RECENTLY, there has been a notably growing interest in system-of-systems (SoS) concepts and strategies. The performance optimization among groups of heterogeneous systems in order to realize a common goal has become the focus of various application areas including military, security, aerospace, and disaster management [1]–[4]. There is particular interest in achieving synergy between these independent systems to enable the desired overall system performance [5]. In the literature, researchers have begun to address the issue of coordination and interoperability in an SoS [2], [5], [6] pointing to the emergence of the concept of system-of-systems engineering (SoSE). SoSE presents new challenges that are related to, but distinct from, systems engineering (SE) challenges. By understanding these differences, appropriate methods, tools, and standards can be crafted in an intelligent manner.

There has been a simultaneous recognition that significant organizational changes are needed in governments and industries, especially in the aerospace and defense areas, to realize these capabilities. The importance of having a group of systems working together as opposed to a single system is to increase the capability, robustness, and efficiency of data aggregation. In the U.S., major aerospace and defense manufacturers, including (but not limited to) Boeing, Lockheed–Martin, Northrop–Grumman, Raytheon, and BAE Systems, etc., all include some version of "large-scale systems integration" as a key part of their business strategies. In some cases, these companies have even established entire business units dedicated to systems integration activities [2].

II. Proposed Consortium

A. Mission

The mission for the International Consortium for System of Systems (ICSOS) is to create a community of interest among science and engineering researchers and to foster proposals and solutions to advance the enhancement of SE to SoSE.

B. Objective

Ultimately, the objective of ICSOS is to enhance the ability of SoS community members to address many new and challenging problems facing the community across a diverse set of problem domain applications. The ICSOS will attempt to bring the best and brightest minds together each year in its annual workshop, creating a venue for funding agencies can obtain neutral views of the experts for their future program planning.

C. Application Areas of SoS

A misleading perception in the early days of SoS was that the application domain is exclusively information technology (IT) and, in particular, the "Internet." This perception is of course far from the truth and one should simply look at the defense and aeronautics community in the U.S. to note the many defense and security scenarios that fall naturally into SoS frameworks (e.g., future combat systems, unmanned air, sea, or land system of vehicles, etc.), as outlined in the following.

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National Security: SoS/SoSE began and is still primarily being applied within the U.S. Department of Defense. Principle areas in which SoS/SoSE is finding early applicability are the national missile defense system of systems; Army's future combat systems development; and the interoperability and integration of intelligence, surveillance and reconnaissance (ISR) systems and command, control, computers, communications and information (C4I) systems and operations. However, it is beginning to be applied in nondefense or security related domains; such as, healthcare, transportation, and space exploration. Yet, any nations' security is dependent upon understanding all the environments of human endeavors and how they impact the people for whom they are responsible. Environments and systems that operate in and on them are growing in scale and complexity as humanity grows and matures. The concept of SoS and the related SoSE endeavors are initiatives to develop processes, methods, and tools for understanding and dealing with the complexities and interactions of multiple domains and levels of uncertainty for addressing large-scale interdisciplinary problems and issues. Developing and sharing the SoS understandings and SoSE processes, methods, and tools within an international consortium forum will benefit both mankind and enhance a participating nations' security posture.

Even further, it is now quite obvious that the SoS concept has applicability beyond defense and IT applications. Here are some nondefense applications areas that ICSOS would also wish to bring to its annual workshop agenda.

III. Nondefense Applications of SoS

Civil Transportation: The National Transportation System (NTS) can be viewed as a collection of layered networks composed by heterogeneous systems for which the Air Transportation System (ATS) and its National Airspace System (NAS) is one part. At present, research on each sector of the NTS is generally conducted independently, with infrequent and/or incomplete consideration of scope dimensions (e.g. multimodal impacts and policy, societal, and business enterprise influences) and network interactions (e.g. layered dynamics within a scope category). This isolated treatment does not capture the higher level interactions seen at the NTS or ATS architecture level; thus, modifying the transportation system based on limited observations and analyses may not necessarily have the intended effect or impact. A systematic method for modeling these interactions with an SoS approach is essential to the formation of a more complete model and understanding of the ATS, which would ultimately lead to better outcomes from high-consequence decisions in technological, socioeconomic, operational, and political policy making context [7] This is especially vital as decision makers in both the public and private sector, for example, at the interagency Joint Planning and Development Office (JPDO) which is charged with transformation of air transportation, are facing problems of increasing complexity and uncertainty in attempting to encourage the evolution of superior transportation architectures [8].

Critical Infrastructure and Air Transportation Security: Air transportation networks consist of concourses, runways, parking, airlines, cargo terminal operators, fuel depots, retail, cleaning, catering, and many interacting people including travellers, service providers, and visitors. The facilities are distributed and fall under multiple legal jurisdictions in regard to occupational health and safety, customs, quarantine, and security. Currently, decision making in this domain space is focused on individual systems. The challenge of delivering improved nationwide air transportation security, while maintaining performance and continuing growth, demands a new approach. In addition, information flow and data management are a critical issue, where trust plays a key role in defining interactions of organizations. SoS methodologies are required to rapidly model, analyze, and optimize air transportation systems [9]. In any critical real world system, there is and must be a compromise between increased risk and increased flexibility and productivity. By approaching such problem spaces from an SoS perspective, we are in the best position to find the right balance.

SoS Standards: SoS literature, definitions, and perspectives are marked with great variability in the engineering community. It is also viewed as an extension of SE to a means of describing and managing social networks and organizations, the variations of perspectives leads to difficulty in advancing and understanding the discipline. Standards have been used to facilitate a common understanding and approach to align disparities of perspectives to drive a uniform agreement to definitions and approaches. By having the ICSOS represent to the IEEE and INCOSE for support of technical committees to derive standards for SoS will help unify and advance the discipline for engineering, healthcare, banking, space exploration, and all other disciplines that require interoperability among disparate systems.

SoS and Healthcare Systems: Under a 2004 Presidential Order, the U.S. Secretary of Health has initiated the development of a National Healthcare Information Network (NHIN), with the goal of creating a nationwide information system that can build and maintain electronic health records (EHRs) for all citizens by 2014. The NHIN system, architecture currently under development, will provide a near real time heterogeneous integration of disaggregated hospital, departmental and physician patient care data, and will assemble and present a complete current EHR to any physician or hospital a patient consults [10]. The NHIN will rely on a network of independent Regional Healthcare Information Organizations (RHIOs) that are being developed and deployed to transform and communicate data from the hundreds of thousands of legacy medical information systems presently used in hospital departments, physician offices, and telemedicine sites into NHIN-specified metaformats that can be securely relayed and reliably interpreted anywhere in the country. The NHIN "network of networks" will clearly be a very complex SoS, and the performance of the NHIN and RHIOs will directly affect the safety, efficacy, and efficiency of healthcare in the U.S. Simulation, modeling, and other appropriate SoSE tools are under development to help ensure reliable, cost-effective planning, configuration, deployment, and management of the heterogeneous, life-critical NHIN and RHIO systems and subsystems [11]. ICSOS represents an invaluable opportunity to access and leverage SoSE expertise already under development in other industry and academic sectors. ICSOS also represents an opportunity to discuss the

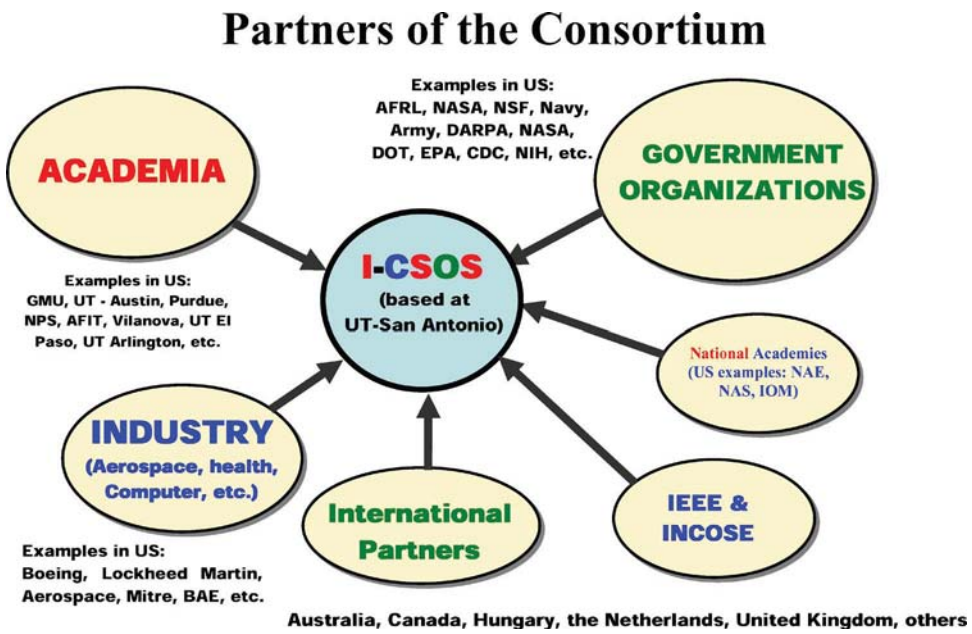

Fig. 1. Structure of ICSOS.

positive and negative emergent behaviors that can significantly affect personal and public health status and the costs of healthcare in the U.S.

Global Earth Observation SoS: GEOSS is a global project consisting of over 60 nations whose purpose is to address the need for timely, quality, longterm, global information as a basis for sound decision making [12]. Its objectives are: 1) improved coordination of strategies and systems for Earth observations to achieve a comprehensive, coordinated, and sustained Earth observation system or systems; 2) a coordinated effort to involve and assist developing countries in improving and sustaining their contributions to observing systems, their effective utilization of observations, and the related technologies; and 3) the exchange of observations recorded from *in situ*, air full, and open manner with minimum time delay and cost. In GEOSS, the "SoSE process provides a complete, detailed, and systematic development approach for engineering SoS. Boeing's new architecture-centric, model-based systems engineering process emphasizes concurrent development of the system architecture model and system specifications. The process is applicable to all phases of a system's lifecycle. The SoSE process is a unified approach for system architecture development that integrates the views of each of a program's participating engineering disciplines into a single system architecture model supporting civil and military domain applications" [12]. ICSoS will be another platform for all concerned around the globe to bring the progress and principles of GEOSS to formal discussions and examination on an annual basis.

Engineering of SoS: As we have noted, there is much interest in the engineering of systems that are comprised of other component systems and where each of the component systems serves organizational and human purposes. These systems have several principal characteristics that make the system family designation appropriate: operational independence of the individual systems, managerial independence of the systems; often large geographic and temporal distribution of the individual systems; emergent behavior, in which the system family performs functions and carries out purposes that do not reside uniquely in any of the constituent systems but which evolve over time in an adaptive manner and where these behaviors arise as a consequence of the formation of the entire system family and are not the behavior of any constituent system. The principal purposes supporting engineering of these individual systems and the composite system family are fulfilled by these emergent behaviors. Thus, an SoS is never fully formed or complete. Development of these systems is evolutionary and adaptive over time, and structures, functions, and purposes are added, removed, and modified as experience of the community with the individual systems and the composite system grows and evolves. The systems engineering and management of these systems families poses special challenges. This is especially the case with respect to the federated systems management principles that must be utilized to deal successfully with the multiple contractors and interests involved in these efforts. Please refer to the paper by Sage and Biemer in this issue [14].

A. ICSOS Participants

Analogous to an SoS itself, the consortium is a construct for the coming together of independent organizations to achieve purposes greater than those possibly met by isolated action. The participant base of the proposed international consortium on SoS (ICSOS), is depicted in Fig. 1.

The central role of the ICSOS is intended to imply that it will act as a neutral (and nonprofit) broker in translating the needs of Government(s) to the field of SoS researchers and foster teaming arrangement from industry and academia to respond to the challenges posed.

Research and development issues such as standards, network centricity, simulation, modeling, system engineering tools for SoS, management of SoS, emergence, evolution, etc., are

among issues which ICSOS can address at its annual international **focused** workshop. Among application areas of SoS, where ICSOS would address are national defense, homeland security, civil transportation, critical infrastructure, healthcare, energy and power grids, manufacturing, space exploration, etc. Other issues of concern for ICSOS could include technology transfer, commercialization of intellectual property in SOS, etc. Efforts will be made to enable active participation and collaboration among IEEE and INCOSE members in this annual event and all ICSOS activities. A collaborative relation between these two organizations will establish a technically and geographically broad foundation for the promotion of SoS practices in SE. The IEEE Systems Council and the IEEE Systems, Man, and Cybernetics have already approved technical cosponsorship of ICSOS. This would make the annual workshop an IEEE technical sponsored event. An opportune time for the Workshop can be either a date concurrent with the annual IEEE SoSE Conference or an INCOSE event.

B. Conduct of ICSOS

Annual Workshop: ICSOS will have an annual workshop each spring, whose technical agenda is directly on the demand of the members of the Consortium. Members will propose items for the annual workshop agenda and a steering committee would review it and approve or disapprove it for the official workshop agenda.

Finances: ICSOS is a not for profit endeavor and will not have any resources except whatever its members are willing to help in keeping it a viable neutral party in meeting the challenges of SoS. We propose an optional membership fee structure for various categories of its members—from large corporations to medium size to small companies and among academia in tier I and tier II group of institutions.

IV. Conclusion

This paper constitutes a white paper to propose the formation of a neutral scientific body to facilitate teaming of industrial and academic scientists and engineers to focus their efforts towards addressing many challenging problems facing the SoSE. This body is being called ICSOS. ICSOS will be a nonprofit body which will bring these groups of scientist and engineers on an annual workshop, which will take place after the annual IEEE SoSE Conference. The long-term effect of ICSOS is to draw the attention of governmental agencies towards addressing key issues and solve the associated challenging problems of SoS and SoSE. The IEEE Systems, Man, and Cybernetics (SMC) and the IEEE Systems Council (SysC) have both agreed to make the ICSOS annual workshop. The first annual ICSOS workshop will be held in Monterey, CA, on June 5, 2008.

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