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How INCOSE's Certification Program has Evolved as a System of Systems

Courtney Wright
INCOSE Certification Program
7670 Opportunity Rd, Ste. 220 San Diego, CA 92111-2222, USA
1-858-541-1725
Courtney.Wright@incose.net

Mrunmayi Joshi
ISAE SUPAERO, France
2000, 4 Avenue Edouard Belin, Toulouse-31400, France
+33-780838752
Mrunmayi.joshi@student.isae-supaero.fr

Abstract

The International Council on Systems Engineering (INCOSE) Certification program began as a subsystem of INCOSE, with only a few external entities involved. The majority of the required capabilities were carried out internally, such testing based on the INCOSE Systems Engineering Handbook. Many capabilities have since been outsourced to independent external agencies such as psychometricians and certificate providers to gain flexibility and simplify operations. As a result, the INCOSE certification program evolved from an INCOSE subsystem to a System of Systems (SoS) with component systems such as universities, exam providers, training providers, and local chapters. This paper discusses the characteristics and challenges of the INCOSE Certification program as a System of Systems, the type of a SoS that best suits the certification program, change management of the certification program, learnings from managing the certification program as a System of Systems, the System of Systems engineering application to the certification programs, and critical problems involved in the certification program's operation and management.

1. Introduction

Many domains, including transportation, defense, healthcare, business, and media, use a System of Systems (SoS), which are made up of independent pre-existing or newly developed systems that collaborate to achieve a unique capability. Growing interconnections and interoperability between different systems make it easier to create an SoS which has distinctive features in addition to the main functions of the systems.

The International Council on Systems Engineering's (INCOSE) Systems Engineering Handbook 4th Edition (Walden *et al.*, 2015) defines SoS as "an system of interest (SOI) whose components are managerially and/or operationally independent system". The US Defense Acquisition Guidebook (DAG) (Dahmann, 2015) defines a SoS as a "set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities". ISO/IEC/IEEE 21839 (Henshaw, 2022) defines SoS as "Set of systems or system elements that interact to provide a unique capability that none of the constituent systems can accomplish on

its own." and the constituent systems as "Constituent systems can be part of one or more SoS." System of Systems (SoS) are made up of independent pre-existing, modified or newly developed systems. This paper uses the ISO/IEC/IEEE 21839 (ISO, 2019) definition of SoS, and constituent systems.

The INCOSE Systems Engineering Professional (SEP) certification formally recognizes a systems engineer's career progression as they develop and apply systems engineering knowledge and practices. The INCOSE Certification program specifies the requirements for each of three stages of a person's competence in systems engineering. It provides assessment against those requirements, assisting in ensuring compliance. Individuals can plan their career path in a way that is resilient to job changes by defining multiple phases that are independent of domain, country, or employer. It provides engineers, as well as their employers and customers, with an independent assessment of individual abilities. It also informs the recipients of the certifications. The INCOSE Certification program collaborates with a variety of external agencies which may or may not be contractually bound, including exam providers, certificate providers, universities, and INCOSE technical operations, to carry out the aforementioned functions, making it a SoS. These external agencies are operationally and managerially independent but work together to contribute to the objective of the INCOSE Certification Program. INCOSE Certification program consists of diverse geographically distributed constituent systems. It is continuously evolving with its constituent system changing. Operating as a SoS provides the Certification program flexibility and lessens the burden of executing all the required tasks by itself, making operations simpler.

On contrary, the INCOSE Certification Program cannot be considered as a system as it does not have an individual life cycle, it does not have clear set of stakeholders, it does not have a clear operational priority or escalation rule, it does not have a clear ownership, and it does not have clear and agreeing purpose and objectives.

The purpose of this paper is to show that the INCOSE Certification program is a SoS and to explore how considering it as a SoS helps to comprehend the issues involved in managing it, as well as to derive potential solutions and improvements. This paper presents the case study of the INCOSE Certification Program as a SoS. This case study is particularly interesting and novel as it deals with application of concepts of SoS and Systems Engineering to a process-oriented SoS with no hardware and limited software components. The literature discusses several prominent examples of SoS like transportation system, integrated defence system, and the internet (Maier, M.W *et al*., 1998) but it does not show case a process-centric organisation such as the INCOSE Certification program as a SoS. The case study consists of understanding the objectives, and capabilities of the INCOSE Certification Program, their allocations to each of the constituent systems, mapping the characteristics of the Certification Program to that of a SoS, challenges posed by the Certification Program as a SoS, recognising what type of SoS is the Certification Program, change management of the certification program, lessons learnt from managing the certification program as a SoS, application of system of systems Engineering (SoSE) to the Certification Program, existing problems in the Certification Program, and potential solutions, followed by future work.

2. Background

Certification is a formal process whereby a community of knowledgeable, experienced, and skilled representatives of an organization, such as the International Council on Systems Engineering (INCOSE), provides formal recognition that a person has achieved competency in specific areas

(demonstrated by education, experience, and knowledge) (Certification Program Overview, n.d.). Certification differs from a “license” that is a permission granted by a government entity for a person to practice within its regulatory boundaries (Certification Program Overview, n.d.). Certification also differs from a "certificate" that documents the successful completion of a training or education program (Certification Program Overview, n.d.). The INCOSE Certification Program offers three levels of certifications corresponding to different stages of career of a systems engineer. The three levels and systems engineering (SE) capabilities of a systems engineer tested at the corresponding level are:

Table 1. INCOSE Certification levels and corresponding SE capabilities verified/tested.

Certification level	SE Capabilities verified/tested
Associate Systems Engineering Professional (ASEP)	Systems Engineering (SE) knowledge
Certified Systems Engineering Professional (CSEP)	SE knowledge, SE experience, and education
Expert Systems Engineering Professional (ESEP)	Leadership, SE experience, and education

2.1 Objectives and Capabilities of INCOSE Certification Program

The INCOSE Certification program has to fulfill several objectives/functions in order to provide the above mentioned 3 levels of certifications. To fulfill these objectives the certification program needs to have certain capabilities which can either be possessed internally by the certification program or can be outsourced to external agents that is the constituent systems. These objectives are solution-neutral. INCOSE offers a solution to meet each objective but also works to identify alternate paths to meet those objectives through other constituent systems. Table 2. Describes the objectives of INCOSE Certification program and the capabilities needed to achieve these objectives.

Table 2. Objectives and Capabilities of INCOSE Certification Program

Serial No.	Objectives	Capabilities
1	Set requirements for each level of certification consistent with ISO standards	Establish basis of certification requirements; Define requirements for 3 levels of certification based on competency framework and ISO standards.
2	Communicate the requirements and certification process	Publish certification requirements for all 3 levels; publish the certification application procedure for all 3 levels of certification
3	Offer assessment against the set requirements to ensure compliance	Define different ways of certification application assessment; prepare knowledge exam questions; provide basis for knowledge exam and certification equivalency; create questions for knowledge exam; beta-test the exam questions; conduct the

		knowledge exam; evaluate the knowledge exam papers; announce the exam results; set requirements for certification equivalency; evaluate and establish certificate equivalency with organizations; offer certification equivalency as an alternative path to certification; review CSEP, and ESEP applications; conduct interviews for ESEP applicants.
4	Track the certification applicants and certified SEPs	Maintain database of certification applicants and certified SEPs; access data of and track the certification applicants and certified SEPs.
5	Increase certification awareness and preparedness (Improve quality of certification applications)	Provide trainings to assist the certification process; create awareness about the certification application and evaluation procedures.
6	Announce/report certification	Create shareable certificates for certified individuals; announce the certification to certified individuals and send their certificates; announce the certifications publicly; publish list of certified individuals.
7	Promote value of certified individuals to companies	Communicate value of certifications through agreements and MOAs with companies.
8	Set requirements for renewal of certification	Provide basis for renewal requirements; Define renewal requirements for 2 (ASEP, and CSEP) levels of certification.
9	Provide means to meet renewal requirements	Provide events and activities through which certified individuals can earn PDUs (Professional Development Units) needed for certification renewals.
10	Provide assessment for renewal of certification	Review the PDUs and details provided by certified individuals; make a decision on renewal of certification.
11	Track renewal applications	Maintain database of certified applicants and renewal applications; track the renewal applications.
12	Report/announce renewal of certification	Create a new (renewed)shareable certificate (with new certification expiry date); announce the renewal of certification to certified individuals and send their certificates; update database with renewals.

2.2 Composition of the INCOSE Certification Program

The certification program began as a subsystem of INCOSE which met most of the capabilities mentioned above such as providing and assessing knowledge exam, beta-testing knowledge exam questions etc. internally without many external entities involved. But it evolved as a SoS by involving independent external entities to perform/meet some of the above-mentioned capabilities in order to meet the objectives of the certification programs. These external entities are the constituent systems of the certification SoS. The Certification SoS includes systems like universities (for Academic Equivalencies), Technical operations for handbook content production, Events, Competency framework, Test provider / platform, INCOSE membership database, INCOSE website, certificate providers, other equivalency providers, training providers, INCOSE local chapters, companies with a memorandum of agreement (MOA), and other events which are independent and have their own purposes integrate to meet this purpose of INCOSE Certification Program.

2.3 Allocation of capabilities to the constituent system

Each constituent system has to meet one or more capabilities mentioned above in order to fulfill the objectives of the INCOSE Certification program. Table 3. explains the capabilities allocated to each of the constituent systems. It also indicates the objectives that these constituent systems contribute to.

Other capabilities such as define requirements for 3 levels of certification based on competency framework and the International Organization for Standardization (ISO) standards, define different ways of certification application assessment, set requirements for certification equivalency, evaluate and establish certificate equivalency with organizations, review CSEP, and ESEP applications, conduct interviews for ESEP applicants, provide basis for renewal requirements, define renewal requirements for 2 (ASEP, and CSEP) levels of certification, review the professional development units (PDUs) and details provided by certified individuals, and make a decision on renewal of certification are met internally by the certification program.

The certification program also shares some capabilities such as create questions for knowledge exam, beta-test the exam questions, announce the certification to certified individuals and send their certificates, communicate value of certifications through agreements and MOAs with companies, announce the renewal of certification to certified individuals and send their certificates with its constituent systems.

Table 3. Allocation of capabilities to the constituent systems of the SoS

Constituent system	Capabilities allocated/met	Associated objectives
Universities	Offer certification equivalency as an alternative path to certification; provide trainings to assist the certification process	Objectives 3, and 5.
Technical operations	Provide basis for knowledge exam and certification equivalency (by producing the INCOSE SE Handbook and learning objectives).	Objectives 1, and 3.

Test provider/ platform	Display knowledge exam questions; provide proctor; conduct the knowledge exam; evaluate the knowledge exam responses; announce the exam results	Objective 3.
Competency framework	Establish basis of certification requirements; Provide basis for renewal requirements.	Objectives 1, and 8.
Events	Provide venue for the knowledge exam; Provide events and activities through which certified individuals can earn PDUs (Professional Development Units) needed for certification renewals; create awareness about the certification application and evaluation procedures.	Objectives 3, 5, and 9.
INCOSE membership database	Maintain database of certification applicants and certified SEPs; Maintain database of certified applicants and renewal applications.	Objectives 4, and 11.
INCOSE website	Publish certification requirements for all 3 levels; publish the certification application procedure for all 3 levels of certification; publish list of certified individuals.	Objectives 2, 6, and 12.
Certificate providers	Create shareable certificates for certified individuals; provide webpage with unique link to certificate for each SEP; announce the certification to certified individuals and send their certificates; Create a new (renewed)shareable certificate (with new certification expiry date); announce the renewal of certification to certified individuals and send their certificates;	Objectives 6, and 12.
Other equivalency providers	Offer certification equivalency as an alternative path to certification; provide trainings to assist the certification process.	Objectives 3, and 5.
Training providers	Provide trainings to assist the certification process; create awareness about the certification application and evaluation procedures.	Objective 5.
Companies with MOA	Provide trainings to assist the certification process; create awareness about the certification application and evaluation procedures; Communicate value of certifications through agreements and MOAs with companies.	Objectives 5, and 7.
Local INCOSE chapters	Provide trainings to assist the certification process; create awareness about the certification application and evaluation procedures; Conduct the knowledge exam; Provide	Objectives 3, 5, 9, 6, and 12.

	events and activities through which certified individuals can earn PDUs (Professional Development Units) needed for certification renewals; announce the certifications publicly.	
Other events	Conduct the knowledge exam; Provide events and activities through which certified individuals can earn PDUs (Professional Development Units) needed for certification renewals; create awareness about the certification application and evaluation procedures.	Objectives 3, 5, and 9.

3. Characteristics of the INCOSE Certification program as a SoS

A typical SoS is distinguished by its constituent systems' operational or managerial independence, geographical distribution, interdependence, emergent behavior, and evolutionary development of the SoS and its constituent systems (INCOSE, 2018). The mapping of these characteristics to the INCOSE Certification program is demonstrated as follows:

3.1 Independence of constituent systems

The component systems of the certification program are operationally and managerially independent. They work towards accomplishing their own purpose and contribute to the capabilities of the certification program. For example: Universities being a constituent system of the certification program contributes towards the objectives of the INCOSE certification program by providing academic equivalency programs as an alternative to knowledge exam while working towards its main purpose of providing education, technical operations contribute to objectives of the certification program by developing the handbook, and learning objectives which serve as basis for knowledge exam, and academic equivalency while working towards its purpose of producing technical documentation, Companies with MOAs with the certification program contribute to the certification program by providing qualified candidates for certification while meeting their own business missions. Neither of the universities, technical operations, and companies with MOAs are dependent on each other operationally/managerially to meet their own purposes.

3.2 Geographical distribution

None of the constituent systems of the certification program are in the same city, nor do they interact in a way where their location matters. All communications are performed independent of their location, generally through asynchronous, written messages. The universities with academic equivalency, companies with MOAs, training providers, other equivalency programs, and the INCOSE local chapters are distributed all over the world (Universities with academic equivalency are distributed in USA majorly). The events that provide written knowledge tests, and opportunities for certified individuals to gain PDUs for renewal are conducted all over the world.

The constituent systems are not only geographically but also culturally and functionally diverse. Each constituent system has unique capabilities, different ways of operation, and diverse individual purposes.

3.3 Emergent Behavior

Emergent behavior is a property generated by interactions of the constituent systems and cannot be produced by an individual constituent system (INCOSE, 2018). The certification program showed the following emergent behavior: As a result of benefits of certification, universities increasingly teaching SE 501 courses using the INCOSE SE Handbook and joining the Corporate Advisory Board (CAB) so they can get Academic Equivalency, and increased INCOSE chapter engagement and event attendance to participate in SEP training, testing, and continuing education. These behaviors are global are results of overall interactions of the systems, and cannot be produced by the universities, and local chapters individually.

3.4 Interdependency

Although the constituent systems of a SoS are operationally and managerially independent, they depend on and interact with each other in order to contribute to the objectives of the SoS. This is no different for the constituent systems of the certification program too. For instance, the Universities, training providers, and the exam providers depend on the handbook, and the learning objectives to meet the capabilities needed from them.

3.5 Evolutionary Development

A SoS evolves continuously over time. As mentioned previously, the INCOSE certification started as a subsystem of INCOSE and evolved into a SoS, the constituent systems have evolved over time too. Several changes occurred to the SoS such as: adding of 2 more levels of certifications (ASEP, and ESEP), providing the certificates in a shareable portable document format (PDF) form unlike in the paper form at the beginning, establishing academic equivalencies as an alternative to taking the knowledge exam, any organization seeking certification equivalency having to meet general requirements in addition to the organization specific requirements, updating the handbook, and learning objectives, providing of web-based knowledge exam in addition to the paper based exam, changing the ESEP telephonic interviews to zoom interviews, transitioning from paid certification reviewers to volunteer certification reviewers, and changing the method of transporting the answer sheets from physically mailing the answer sheets to the evaluation center to scanning and sending it through mail for evaluation. There are many drivers to these evolutions like cost saving, time saving, simplification in processes, and evolution in technology.

Since the INCOSE Certifications program possesses all these characteristics of a typical SoS, it can be established that the certification program is a SoS indeed. This will be further confirmed by discussing the challenges of a SoS that the certification program faces.

4. Challenges due to being a SoS

Working as a SoS can provide flexibility and simplicity, but it also brings many pain points/challenges as it involves many existing constituent systems. Here are the typical challenges of a SoS that the certification challenge has faced:

4.1 Capabilities & Requirements

The constituent systems have their own needs in addition to meeting the capabilities needed by the SoS. Sometimes their own needs contradict with the capabilities needed for the SoS which might

affect the operation, constituents, and performance of the SoS. For instance: (1) During COVID crisis, the test providers continued to provide facility-based exams (complying to COVID norms) meeting their objectives and needs, but the certification program needed them to provide remote testing capability. The online tests provided by the test providers did not meet the capabilities needed by the certification program which resulted in change of the test providers. (2) Changes in Defence Acquisition University (DAU) certification program was not in compliance with the equivalency requirements of the certification program, which resulted in the modified certification program not being equivalent to the INCOSE Certification program.

4.2 Autonomy, interdependencies, and emergence

Although independent and autonomous there are complex interdependencies within the constituent systems at different stages of the SoS. These interdependencies result in emergent behaviour at the SoS level which are difficult to anticipate. For examples: (1) As a result of benefits of the certification program certain companies required their employees and subcontractors to have INCOSE SEP certification. This resulted in backlash towards the certification. (2) Due to increase in the number of trainings to support the certification process, the quality of the certifications suddenly raised increasing the expectations of the reviewers from a certification application. This impacted the applicants who did not opt for any trainings for certification, as their applications could not meet the raised expectations of the reviewers.

4.3 Validation

The constituent systems have unsynchronized development cycles. The operation of the certification program and the contribution of the constituent systems have to be validated, especially after changes in the certification programs and/or the constituent system, which is expensive, and time consuming. For example: The change in handbook has led to the certification program to develop new exam items. To validate this change beta testing of the exam items will be performed. The training providers are a constituent system, but their contributions (trainings provided by them) are not validated by INCOSE due to high cost, and time required.

4.4 Authority

Lack of common authority makes it difficult for constituent systems to collaborate effectively. The certification has no control over the timeline for implementation of changes in the constituent systems. The certification program does not have authority over timeline of handbook update. For instance, delays in timelines of handbook update might result in delay in preparation and beta testing of new exam items, and delay in transition of academic equivalencies, impacting the certification program. The certification program does not have complete control over updating of constituent systems. The certification program can object to the changes proposed in the handbook, propose changes but does not have authority to enforce changes.

5. The INCOSE Certification Program as a type of SoS

An acknowledged SoS has recognized objectives, a designated manager, and resources, while maintaining the operational, and managerial independence of the constituent system. The SoS manager does not have power to control any of the constituent system, but they can influence the development, and update of the constituent system (Dahmann, 2015). This description fits the

certification program well, as it has defined objectives, and dedicated resources with a manager. The SoS manager has influence over constituent system, for example: the certification program has power to oppose, or propose changes in the handbook but cannot accept or reject any changes, the certification program collaborates with the universities to meet the academic equivalency requirements, but the certification program does not have any control over the universities other than the ability to grant or reject the academic equivalency. The certification program lies in between the directive SoS type, and the collaborative SoS type, hence it is an acknowledged SoS.

6. Change management in the Certification Program

The certification program, and its components are continuously changing. These changes can affect the performance, operation of the SoS, and the contribution of the other constituent systems. For example: Update in the handbook results in change in knowledge exam, changes in academic equivalency, and changes in trainings provided by training providers. Hence, change management is done by having processes/plans in place to deal with the changes, and providing time for other constituents to adapt to the changes. Few examples of plans/ processes for managing changes are: (1) There is a plan in place to manage update of INCOSE SE Handbook from 4th edition to 5th edition. (2) If an equivalency organisation decides to make changes to their program, the organisation must submit the changes to INCOSE for review of the equivalency. (3) There exist requirements for proctoring companies, in case of change, the new proctoring company needs to comply to these requirements. Providing guidance and time to adapt to the changes helped in these past situations: (1) Guidance given to academic equivalencies on compliance with updated learning objectives and handbook (5th edition). (2) In case of changes in application forms, training providers are given 12 months to update their training materials accordingly. (3) During the first year of COVID, in-person activities were abruptly cancelled, affected individuals' opportunities to earn PDUs. SEPs were allowed to renew with fewer PDUs to accommodate for this surprise.

7. Learnings from viewing the certification program as a SoS

The INCOSE Certification Program has examples of implementing many keys to effective SoS leadership. These include recognition of incompatibility, recognition of unscalability, differentiating requirements from implementation, and signing short-term contracts. The Certification Program is fortunate to have engaged stakeholders from diverse communities. Suggestions from these communities are frequently not scalable or in some other ways do not fit with a global SoS.

In 2016, INCOSE learned that few certification candidates in China took the INCOSE knowledge exam at test centers in that country, even if the candidates had successfully completed an exam preparation training course. One obstacle was that the exam registration was to be completed through a website that used Google Maps to search for the closest testing location. Despite this test center provider having facilities in China, they failed to recognize that the Google Maps widget did not work on that country's internet. INCOSE Certification ended up finding an expensive alternative to that test center provider because it was not usable in one country. INCOSE recognized that the system was not compatible with the SoS that desired a solution that would work for all candidates.

INCOSE tried in 2021 to expand on a pilot program to interview CSEP candidates about their SE competency, as a supplement to their individual application for CSEP. This process had worked well in its first pilot within the UK, but it became very difficult to implement on a global scale. Coordinating across time zones and communicating the updated application form instructions to candidates from various backgrounds was too resource-intensive to scale up that process across all of INCOSE.

Another example of global scalability failing was not seen as a fault in scaling but rather as a fault in defining what should be scaled. The requirement that all ASEPs and CSEPs pass the knowledge exam (which is written in English, delivered with a time limit, and presented with multiple-choice options) put some candidates at a disadvantage. The root cause of the problem was that the requirement was written incorrectly. The requirement should not have been "The candidate has passed the INCOSE knowledge exam." It should have been: "The candidate has verified knowledge of the INCOSE Systems Engineering Handbook." This requirement is scalable and INCOSE has recognized over a dozen different ways to meet the requirement through its Academic Equivalency program, as well as other equivalencies specific to particular languages or domains. This problem can be solved through the SoS Engineering practice "Understanding capability objectives" (refer section 8).

A final key to success with SoS coordination relates to the asynchronous development schedules of SoS constituent systems. INCOSE has resolved this in its agreements with universities and corporate partners, by setting time-bounded contracts. These force the review of requirements and active decision to renew agreements. This reduces the psychological aversion to raising concerns that can exist when it is easier to let problems or inefficiencies continue. This problem can be solved through "Orchestrating upgrades" (refer section 8).

Viewing the INCOSE Certification program has an impact on its performance. For example, one of the key performance indicators of the Certification Program is the number of certified SEPs every year. By outsourcing the capability of "Offer assessment against the set requirements to ensure compliance" to SEZERT certification equivalency in Germany in addition to providing the traditional assessment path, the total number of certified SEPs in Germany for 2021, and 2022 are 38 (23 from equivalency), and 43 (16 from equivalency) respectively, which are higher than that of France which does not have any alternative assessments, 33 in 2021, and 35 in 2022.

8. SoS engineering practices applied to the Certification Program

System of Systems Engineering (SoSE) is about the integration of independent and operable systems networked together to provide new capabilities. Its focus is on the behavior of the System of Systems (SoS), i.e., on synchronization, interoperability, and interface management between the constituent systems.

Following are some of the key elements of SoS engineering applied to the certification program (INCOSE, 2018):

1. Understanding capability objectives: It is important to understand the capabilities needed from the constituent systems by the SoS, to ensure that the constituent systems are able to meet these capabilities. While this is briefly described in section 2, it is documented in detail in the certification procedures.

2. Understanding systems and relationships: This involves understanding the interactions between the constituent systems, and between the constituent system and the SoS. These relations are documented in the certification procedures.

3. Developing & Evolving an SoS Architecture: The architecture of the SoS should include the concept of operations, systems involved, their functions and interactions, and functionality of SoS with the data flow. The development of the certification architecture has been initiated.

4. Orchestrating Upgrades: Any changes, and updates in the SoS, and the constituent systems in managed by the change management plan described in section 6.

9. Open problems and future work for the INCOSE Certification Program

9.1 Problems

Even though some of the SoS engineering practices have been applied to the certification program there are following open problems:

1. There are different ethical norms due to geographical distribution, and cultural diversity of the certification applicants. This implies that there is different definition of cheating throughout the world. Hence, maintaining fairness throughout the certification process is difficult.

2. Opportunities to collect PDUs to renew certification depends on various factors such as availability and accessibility of trainings, and events, and mindsets of applicants from different regions, cultures, and economic conditions.

3. Current cost of certification process might seem higher to applicants from some regions due to higher currency exchange rate or lower incomes. This makes the certification less equitable to all.

4. Language barrier affects the certifications as the knowledge exams only happen in English, and the handbook is released in English and needs translation for several region. Translation of handbook is particularly tricky because a translator might align the content of the handbook to the work practices of that region rather than the actual content of the handbook.

5. Data security requirements vary with countries, regions, and organization. Handling varying, and sometimes conflicting data security requirements is an open problem especially when different requirements arise at different times.

Most of the above problems stem from the diversity and geographical distribution of the SoS. Apart from the listen problems, issues like incompatibility between constituent systems, emergent behavior, unsynchronous upgrades, and changes in the SoS and the constituent systems remain open issues.

9.2 Future work

In order to deal with problems associated with cultural, or situational diversity, two approaches can be taken: (1) Creating customized requirements: For example: to deal with the issue of cost of certification being high for applicants of certain region can be solved with differential pricing, similarly, the issue of variation of opportunities, and motivation for collecting PDUs can be solved by interacting certified individuals of different regions, cultures, industries, and age groups in order to understand their perspective, and problems to better device the PDU requirements for them. The issue of language barrier can be partially solved by establishing academic equivalencies in different countries, providing courses in their own languages. (2) Having flexible or reduced requirements to bridge the gap: The problem of varying understanding of cheating/malpractice can be reduced by simplifying the application steps making it improbable to cheat, for instance: to avoid copying/cheating in the reference forms, the applicants can copy and paste the parts of their experience forms into the reference forms for the references to just confirm the experience. To solve the problem of data security, the data required to be shared between the parties can be reduced to absolutely necessary information. This information has to be shared through authorized channels by authorized personnel.

The problems related to emergent properties, evolutions, and changes in the SoS can be dealt with by applications of Model-Based Systems Engineering (MBSE). Several possible events of SoS can be modelled from the past data and simulated to anticipate the emergent behaviors. This can help in mitigating any risks associated with the emergent behaviors. Through modelling of the SoS, the constituent systems, and their interactions an impact analysis can be run if there is any change in the constituent systems or the SoS to understand the effect of this change on the other constituent systems, and the SoS.

The application of MBSE to a certification program (SoS) may provide the following benefits (Chen, and Mark Unewisse, 2012): e establishing common SoS practices, assisting in the generation of artifacts, managing interdependencies and agreements between constituent systems and the SoS, supporting trade-offs, monitoring and managing the SoS's status and performance, anticipating emergent behaviors, monitoring and tracking the status of constituent systems, and analyzing the impact of constituent system change on the SoS.

The MBSE tools and methodology used would be heavily influenced by the purpose of this activity and the expected outputs from the models and simulation. However, here are a few examples of activities that can be carried out (E. Honoré-Livermore et al., 2021):

1. Simulation of the SoS's capabilities and objectives.

2. Simulation of various operational concepts.

3. Modeling of constituent systems to determine and define interfaces and how constituent systems meet the SoS objectives.

4. To reduce the likelihood of undesirable effects, the model should support simulation or prediction of emergent behavior.

5. SoS testing and validation modeling should ensure traceability from top-level objectives to lower-level requirements and functional elements of the constituent system.

Although MBSE provides many benefits but there are some challenges that can arise while implementing MBSE to a SoS, such as (E. Honoré-Livermore et al., 2021):

1. The purpose of the modelling effort and expected insights must be clearly defined at the onset of the effort.
2. The architecture can quickly become complicated.
3. Clarity on what is the "system of interest" is needed.
4. The level of detail up to which the constituent systems should be modelled is not clear.
5. Information needed from the developers/owners of the constituent systems is not clear.

Modelling efforts towards this have begun. Figure 1. is a class diagram representing the elements of the certification program and their associations.

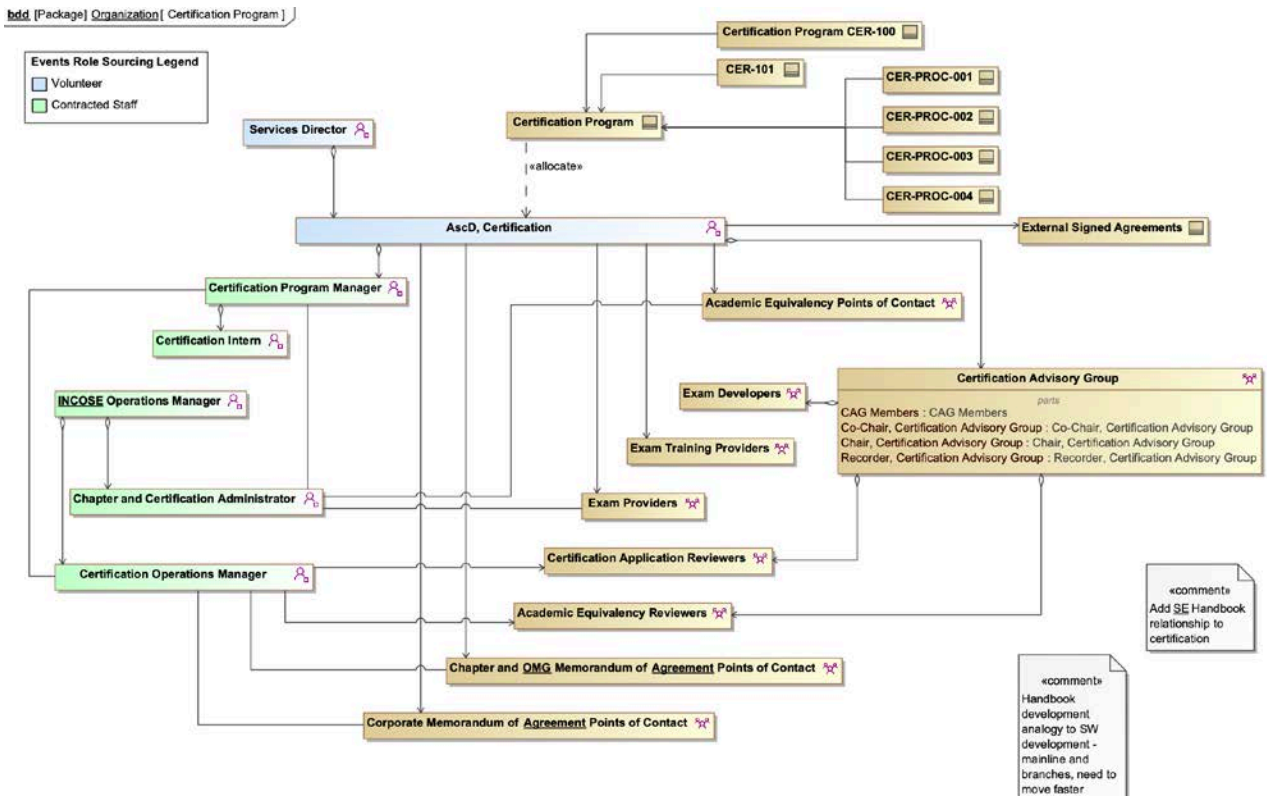

Figure1. Class diagram of the certification program.

10. Conclusion

Although the INCOSE Certification Program has been functioning as a System of Systems prior to the authors identifying it as such, there is value in recognizing its nature so that it can be more effectively managed. Some of the SoS characteristics have always existed within the INCOSE Certification Program – particularly its geographic distribution – and no action is required to optimize that. Emergent behaviour and interdependency are important to keep in mind, as they drive the need for close tracking and communication with constituent systems. Training providers have taken on these functions of tracking and communicating between individual stakeholders and the Certification Program. They could not have been assigned this role but all parties benefit from their service. Modelling system interactions is also an important mitigation to the challenge of asynchronous development across constituent systems. Models and relationship management are both appropriate activities for the Certification Program Office to coordinate. This combination of people, processes, and tools is a useful contribution as a case study in the development and operations of a System of Systems. This case study can motivate other process-oriented organisations like the INCOSE Certification program as a SoS. They can especially benefit from understanding the capabilities that are needed by the organisation and finding existing systems that can meet these capabilities.

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Biography

Courtney Wright is a Certified Systems Engineering Professional (CSEP) and the Program Manager for INCOSE's Certification Program.

Mrunmayi Joshi is an Associate Systems Engineering Professional (ASEP) and a master's in aerospace engineering student at ISAE SUPAERO, France.