Environment in System of Systems (System of Systems)

Thomas Tenorio reflections from World Café discussions

The discussion of Environment was confusing to each of the three groups. People interpreted environment to mean what they do – whether it was a warfighter, a tester, an M&S person, etc. This was not surprising given the fact that even in the ISO standards there are at exist at least 20 different takes on environment and context.

Environment, Ackoff's framework and Senge's archetype

Ackoff's definition of environment as it relates to a system (or a system of systems).

A system is a set of interrelated elements.

The state of a system at a moment of time is the set of relevant properties which that system has at that time.

The environment of a system is a set of elements and their relevant properties, which elements are not parts of the system but a change in any of which can produce a change in the state of the system.

The state of a system's environment at a moment of time is the set of relevant properties at that time.

A closed system is one that has no environment.

An open system is one that does.

A system (or environmental) event is a change in one or more structural properties of the system (or its environment) over a period of time of specified duration; that is, a change in the structural state of the system (or environment).

In an imperfectly organized System of System even if every system performs as well as possible relative to its own objectives, the total system will often not perform as well as possible relative to its objectives.

In discussing system problems faced by organizations of systems, Peter Sengin makes frequent reference to a system archetype called "The Tragedy of the Commons" which was first identified by ecologist Garrett Harding (1968). This archetype is seen as especially useful for dealing directly with problems where apparently logical local decision-making can become completely illogical for the larger system.

A frequently missing element in the discussion of System of Systems is environment.

The Test and Evaluation (T&E) Environment

There are two major considerations in the discussion of environment when it comes to Test and Evaluation.

1. The Warfighter Environment
2. The T&E Environment

It is impossible to replicate the Warfighter environment since the Red force represents an unknown.

The warfighter faces a world where capability delivered by a System of Systems will ultimately be tested by the adversary. The T&E community attempts to address risk by providing knowledge using a variety of pseudo-environments to reflect the complexity of environment.

The T&E Mission

T&E is performed to validate the hypothesis of system right and right system.

T&E informs the developer whether a system addresses the problematic situation.

T&E has value when it facilitates early discovery of problems and leads to requisite development.

T&E of System vs. SOS

The focus of T&E has often been to replicate environment to T&E a single system.

The big question is how to we representing environment for the T&E of SoS?

Today the T&E community represents environments in three ways:

- Live
- Virtual (modeling and simulated)
- Live/virtual mixed called Constructive

Representatives from each community were present to acknowledge the need for all three approaches. The consensus however is that live T&E was too expensive and we need to focus on more virtual T&E. The warfighters however justified live testing as the only way to determine if systems were actually operational.

There also seems to be general consensus that T&E is too expensive but understood that removing the 5-25% of budget for T&E did result in major failure to deliver 40% of targeted systems along with huge blowouts in cost, scope, and schedule.

The huge reliance on M&S in Future Combat Systems and the cancellation of the program has resulted in a demand for three live tests per 18 month capability set.

The discussion of environment led to the discussion of additional environment consideration for those not clear on the T&E terminology of live, virtual, and constructive.

- The Imagined World
- The Networked World
- The Real World

The imagined world includes T&E using modeling and simulation of a representative environment suitable for training, stimulation, emulation, and engagement prior to live events.

The networked work includes T&E in the cyber-world with SOS agents operating in an environment that includes blue and red elements.

The real world includes T&E of the SOS by the adversary, followed by the warfighter, blue teams, red teams, the various system testers making up the SOS with the understanding there is no overall SOS T&E overseer.

A Review of Group Comments

There would be power in building greater ties within the larger testing community as an enterprise test capability devoted to knowledge maximization during field test events.

The challenge of SoS testing is to shift from T&E focusing on “connectivity” to T&E of “interoperability” by maximizing the contributions of a net-centric T&E community supporting more free flow of information, capturing and distilling information, assigning relevancy, and overall, sharing of challenges-to-solutions.

Some common challenges are likely to be: issues of funding; levels of information assurance; testing at the micro and macro component level; and, identifying the appropriate testing intersections of design and development.

The T&E community should try and infuse a scope of abstractions into the process. Levels of abstraction using simulation, emulation, and modeling, for instance, could help to build confidence levels early on. The testing community might want to develop confidence levels for SoS as its measures, versus the current risk posture against requirements. String event tests could be used to define confidence levels.

Need for a ensure feedback loop exists from users in the field of operations with a focus mission-based T&E as a means to try collect data from environments that are anticipated and unanticipated.

ITEA Conference on T&E of SOS
1/22-27/2012
Town Hall & World Cafe

T O W N H A L L

John Thomas Notes

The following distinctions arose:

- SoS terminology and context
  - The common definition of a System of Systems (SoS) as "A SoS is built from a group of standalone systems" is inadequate to guide the SE and T&E communities
  - Additionally, non-technical attributes are needed to understand SoS characteristics which frame future SE and T&E challenges
  - Characterizing the non-technical attributes to differentiate various groupings of standalone systems is critical to develop a semantic for SE and T&E community investigation
  - Once the non-technical attributes are described, the SE and T&E community should adopt different terminology for the grouping of standalone systems to avoid confusion.
  - This means one grouping of standalone systems should be labeled SoS. The other groupings should be labeled something else other than variants of SoS
  - It was noted that in some examples of "groupings of standalone systems" there appeared a stringing process that knitted standalone systems together. This stringing process felt like top down design. While other SoS examples seemed to portray an aggregation of standalone systems through a composition process. The composition process felt more like a bottoms up configuration management effort.

  Overall, the term "species" seemed like it might be a way of categorizing different SoS and tests for those SoSs. (Tim Scully)

- Serious SE and T&E Environmental analysis can go forward once the SoS differentiation and terminology is sorted out.
  - Clearly defined differentiated groupings of standalone systems will help the SE and T&E community understand what needs to change in the overall SE and T&E environment to more successfully deal with each type of SoS.
  - The overall environment includes acquisition process, SE process, T&E process, PM process, the national test ranges, the PMO attitude about cost vice investment, …
  - SE and T&E doctrinal approaches will evolve as well

- Major changes in SE and T&E approaches will require an evolution across and within each national test range to get the most understanding of the benefits and drawbacks of these differentiated groupings of standalone systems.
- The SE and T&E analysis process will evolve based on these SoS differentiations, and the SE and T&E community must be ready to extend data management to data & knowledge management and to use different technologies of analysis tools.
- The value proposition of SE and T&E will evolve based on the production of data and knowledge as part of the T&E activity – but it is very possible that the value proposition will not be recognized based on the long term historical community understanding of what SE and T&E do and what it doesn't do.

Come up with an appropriated definition / understanding of Return on Investment as it applies to T&E of SoS. (Tim Scully)

- Kathy Smith stated that there is a DISA study that discovered
  - 60% of fielded IT systems were used as intended (i.e. what the concept of operations and system requirements specified)
  - 40% of fielded IT systems while useful, were useful for different reasons and were not being used as originally intended (i.e. what the concept of operations and system requirements specified)
- Kathy and Jack Ring also stated that there is a Defense Science Board report spanning 2001 thru 2007 that reinforced (in general) the DISA findings.

Tom Tenorio notes:

Impediments:
T&E people need a better understanding of SOS
T&E people need a better understanding of Autonomy?
T&E people need a better understanding of Cyber?

Hampered by Culture, Contracting, Legacy, Doctrine, Everybody in charge
SE Vee diagram misleads that T&E occurs only on right side (John Thomas also made this point from the floor during a keynote address).
Have not quantified a Value Proposition of T&E, particularly for SOS, e.g. ROI and Examples of successful results
T&E currently implies large investment in T&E infrastructure (see Test Points)
Spend a lot on T&E because SOS of interest wasn't system engineered in the first place (see DoD Guide for SOSE)
Waste a lot of T&E $ (40%?) by initiating test when systems are not ready.

Opportunities
Like Quality, T&E is Free.

Project overruns can be largely avoided with Independent and objective T&E from Day 2 to Year N, particularly if the purpose of T&E is System Readiness Assessment.
Identify classes and types of SOS, e.g., Targeted, Pursuit, Value-seeking, and test accordingly.
Ensure that SE of SOS conforms to Wymore's Six

- I/O
- Performance
- Cost
- Technology
- Test
- Trade-off Gradients

Test Points: In the old days electronics had Test Points built in so that users could see whether things were proper. These considerations were honored by the original equipment designers. Ensure SOSE provides for the inclusion of adequate Test Points and self-test in all systems (see Wymore's Six). This provision by Original Equipment SE will greatly reduce the cost and cycle time of SOS T&E. Then why does the Guide for SOSE omit the designation of Test Points?

The GSE on an aircraft can be a rather large, complex system in its own right.

How would you like to drive a car that had no instrument panel? The on board computer monitors a modern automobile for dozens of troubles. The Service Dept. can plug in to a receptacle under the dash and read out the history of trouble codes.

(Note that increasingly autonomous systems will already have this).
As we move on to T&E of autonomous systems they will have an on board self-test capability. The system should have a port for T&E. Further, one of the conclusions by T&E must be about the efficacy of the self-test capability.

W O R L D C A F E

John's Thomas Notes

During the **World Café** session – three table conversations were focused on the following discussions topics:

1. How many types of SoS's are there?
2. If there are multiple types –
    a. What characteristics differentiate the SoS's.
    b. What are the greatest changes in the SE and T&E environments for SoS's.
    c. What are the big picture differences in mindsets that the SE and T&E communities should be sensitive to for SoS's.
3. Commonalities of any SoS
    a. Each SoS is built from a grouping of Stand Alone Systems
    b. Each Stand Alone System Most Often has:
        i. Independent Program office Authority

ii. Independent Funding lines
iii. Independent Mission Capability
iv. Independent Operational concepts
v. Independent System Requirements & Specifications
vi. Independent Schedules
vii. Independent Metrics of Success
viii. Independent users, operators, and stakeholders
ix. Independent contracts focused on the delivery of
x. Was not developed (or being developed) and fielded (or being fielded) in context of any SoS concept

4. Types of SoS's -- At least 3 "groupings of standalone systems" exist.
    a. SoS "A" unique properties
        i. Success is defined with an objective (not subjective) criteria associated with a concrete operational need.
        ii. The operational need serves as a basis to develop operational capabilities, system requirements and technical specifications for the SoS.
        iii. The operational need easily translates itself into solutions through a "implement me a technology"
        iv. Many times a Formal authority (will be called PMO in these notes) is chartered to address the SoS operational need
        v. Many times a Formal/Informal funding line is established to address the SoS operational need
        vi. Many times a formal/informal authority guides or drives modification of standalone systems and implements some type of integration framework to tie the standalone systems together.
        vii. PMO design activity focused on:
            1. Generating a SoS design targeted at addressing pre-define operational need
            2. implementing a SoS design from existing Stand Alone Systems
            3. implementation of SoS design always requires some modification of Stand Alone Systems and the development of an integration framework to tie the Stand Alone Systems together.
            4. Modeling and Simulation - when used - is a part of the SoS design activity. SoS design rarely relies on existing Stand Alone Model and Simulation activities.
        viii. The modification of standalone systems and the integration framework is performed in the context of a schedule of tightly coupled activities and tightly coupled funding lines

ix. The resulting SoS is always composed of a clearly defined number of Stand Alone Systems, has a predefined number of Interfaces, has a clearly defined boundary

x. The SE and Test & Evaluation organizations use the predefine operational need and documentation as a standard to help plan and conduct their activities.

b. SoS "B" properties

i. Identical to SoS "A" properties except for

ii. No coupled schedule activities or funding lines.

c. SoS "C" unique properties

i. Success is often defined with a subjective (not objective) perspective. Sometimes called a "mission gap ".

ii. The mission gap often makes sense only from the context of a very senior operational stakeholder/user

iii. The mission gap provides a compass heading (not a standard) for use in guiding which standalone systems might have utility as part of the SoS

iv. Many times no formal authority (will be called PMO in these notes) is chartered to address the mission gap

v. Many times no formal/Informal funding line established focused on addressing the mission gap

vi. Many times no formal/informal funding line & authority exists as an integrating force to guide and support modification of any standalone system within the SoS

vii. Often times a formal authority exists to invite standalone systems to be involved in an interaction with other standalone systems

viii. Often times invited standalone systems go through a pass/fail set of criteria before they are allowed to interact with other standalone systems in a controlled environment. This criteria is used to establish the ability of standalone systems to communicate with each other. The pass/fail criteria ranges from physical up through various logical layers of communication mechanisms.

ix. Oftentimes invited standalone systems (that perform similar functions) are assessed against each other using some subset of standalone requirement metrics before they are allowed to interact with a broader group of standalone systems

x. Many times Modeling and Simulation capabilities do not exist to support analysis of the standalone system interactions.

xi. There is no real SoS design activity focused on choosing what standalone systems comprise the SoS.

xii. More often the design activity is replaced with a configuration management activity that keeps track of numbers of specific standalone systems within the SoS.

xiii. A configuration of standalone systems is then put through pre-choreographed, orchestrated, activities.

xiv. The orchestrated activities are constructed to assess several different objectives:

1. Subjective success toward closing mission gap (many times the subjective criteria of "good enough" is used vice a determination of "mission gap closed")
2. Data and downstream analysis is further focused on:
    a. associating more objective criteria with the mission gap
    b. comparing standalone systems (that perform similar functions) against each other

xv. There is no static definition of the SoS. The SoS is dynamically defined by the configuration of the standalone systems used for the specific activity.

1. The assessment of the Dynamic SoS feels more like looking at a "mission gap" gauge that moves between "better or not as good" as a function of configuration of standalone system

xvi. The assessment & observation process of the dynamic SoS could support the concept of discovering "new or unintended capabilities".

xvii. Changes in standalone systems occur within very loosely coupled (or no coupled) schedule activities and funding lines.

xviii. The result of this type of SoS is there are no clearly defined number of Stand Alone Systems. No clearly defined number of Interfaces. No clearly defined boundaries.

xix. The SE and Test & Evaluation organizations have no predefined operational need and documentation at the SoS level to use as a standard to help plan and conduct their activities.

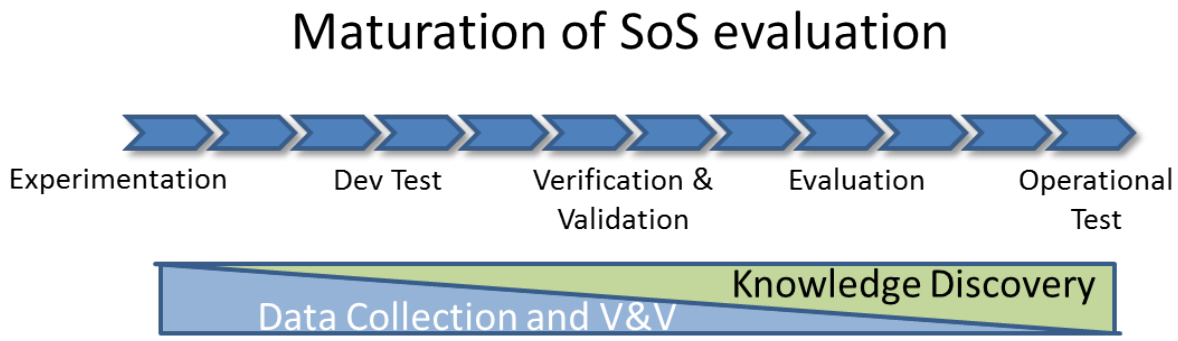
xx. There is an evolution of subjective and objective criteria to help frame success criteria in this kind of SoS.

xxi. After Multiple SoS configurations participate in multiple pre-choreographed activities -- there is a growing base of objective criteria and a growing base of subjective criteria.

xxii. Initially, the participants of this kind of SoS activity initially feel as if they are discovering and reporting the results of experimental activities.

xxiii. Over time and with the addition of more objective criteria, the participants of this kind of SoS activity feel as if they are involved in capture the results of a prototyping activities

d. SoS "D" properties
    i. There is no success criteria
    ii. Many times there is no organization chartered to invite standalone systems to "play"
    iii. Many times there is an organization chartered to develop an environment and publish standards that allow standalone systems to use for interaction with each other.
    iv. Many times there is an organization charted to develop pre-choreographed activities.
    v. Many times there is an organization (same or different than above) that is chartered to monitor the capability of each standalone system and the combined capability of standalone systems against (pre and un) choreographed activities
    vi. Many times there is an organization chartered to publish the results of the monitoring activity to the community of environment builders, standalone system owners, stakeholders, users, and operators.
    vii. There can be an organization that formally analyzes the resulting data to report on "best of breed;" discovery of "new or unintended capabilities;" recommendations on changes to pre-choreographed activities to provide insight into robustness,



survivability, safety, …

    viii. There is an evolution of subjective and objective criteria to help frame SoS success in this kind of SoS
    ix. The result is this type of SoS had no clearly defined number of Stand Alone Systems. No clearly defined number of Interfaces. No clearly define boundaries.
    x. The SE and Test & Evaluation organizations can have clear roles in support of observing and capturing the emergence of system behavior. Neither of their processes support doing so

xi. The participants of this kind of SoS activity feel as if they are always discovering and reporting results from experimental activities.

5. **Greatest changes in SE and T&E environments**
    a. SoS's of Type "C" and "D" above will require more and more collection of data without a priori detailed understanding of what the data is to be used for at the time of collection.
    b. Data and information schema will dynamically change on a daily or weekly basis, therefore hampering the use of only relationally managed data structures. More and more reliance on Cloud Computing (columnar managed) data architectures will be required.
    c. The data management and analysis tools to support this must evolve to support both relationally managed and cloud managed databases.

    1 - Requirements at a SoS level
    2 - Nomenclature / definitions/ lexicon
    3 - Development of knowledge (Tom Tenorio stated a 5% reduction in testing resulted in a 40% reduction of delivered capability – I'm not sure of his source)

6. **Big Picture differences**
    a. The SE and T&E framework of thinking based on "we know what we know" and "we know what we don't know" is a still useful point of departure for Type "A" and "B" SoS's. However, this framework of thinking must evolve to embrace "we don't know what we don't know" to provide efficient and powerful insight into the Type "C" and "D" SoS's
    b. The definition of what the SE & T&E do that is valuable to their stakeholders must be rebranded to ensure recognition of how they contribute, and an understanding of the value they provide to the overall acquisition and sustainment communities.
    C. The concept of ROI as it related to T&E was discussed in multiple settings. R)I might be defined by finding other ways of using the system than the way the designers originally intended. – Peter Drucker was said to have said, 'systems are used for 9 times more uses than originally intended'.

Jack Ring's notes

Table 3 addressed the idea that T&E must deal with Known, Unknowns and Unknown Unknowns. The three sequential groups elucidated ten points.

1. The idea may be better addressed a little more personally as Know, Don't Know and Don't Know Don't Know. Further, these states of knowing become more clear when we recognize that Know consists of not only of truth but also, as Will Rogers warned, 'what we know that ain't so.' Also that Don't Know includes That we don't know and What we don't know. Likewise, Don't Know Don't Know includes That and What.

2. Real world situations include not only what T&E people should strive to know about a) the system of interest, SOI, but also about b) the T&E system they devise to exercise the SOI, c) the Stakeholder desires and even d) the context or intended usage of the SOI. Also very important is what T&E people should know about e) themselves, including that/what they Don't Know and that/what they Don't Know they Don't Know. Some of the participants evidenced a little cognitive dissonance regarding the DKDK about themselves.

3. Ain't so, DK and DKDK increases as the problem system increases, particularly to SOS and the span, scale and pace of change of brigade-scale SOS.

4. This highlights the importance of T&E people discovering the dynamic and integrity limits of the SOI by devising a T&E system that has the requisite variety to do so.

5. Know is not all the story. Do is important as well, as in Do, Don't Do and Don't Care, (the latter also known, unfortunately, as Close Enough for Government Work). Also this raises the issue of who, how, what, when, and where the T&E system is T&E'd and particularly the who, how, what, when, and where the SE of T&E is T&E'd. An interesting corollary is the who, how, what, when, and where the SE of the SOS is T&E'd. Unless that SE of the SOS is reasonably well performed the T&E of the resulting SOS will be fraught with aborts, problems and overruns in cost and schedule. T&E should attend to the system that produced the SOS as well as attending to the SOS.

6. Don't Care surfaced a realization that SE, the 'profession,' must abide by a Standard of Care similar to what PE's have. An ethics statement does not suffice.

7. A T&E activity and the T&E community must learn at the pace of change and knowledge discovery. Practices such as After Action Reviews and Reflection time must be adopted.

8. The current DOD efforts in T&E of SOS, e.g., NIE, could benefit by 'benchmarking' how it was done and is being done in other venues such as Industrial Supply Chains today, Computer Integrated Manufacturing in the 1980's and the USN's Willoughby Templates of the late 1970's.

9. The relationship of T&E vis a vis IV&V must be clarified else gaps and unnecessary redundancies will arise. The principles of Lean SE are relevant.

10. The SE of T&E of SOS must acknowledge (know) and honor (do) multi-facet, dynamic constraints such as Range Safety, FCC spectrum usage, FAA airspace usage, DHS public safety, etc.

Apologies for any points missed in this report.

Steven's notes:

Tom Tenorio's Environments table:

- There would be power in building greater ties within the larger testing community. Those ties were described metaphorically as "interoperability," meaning to have greater communications among testing organizations: more free flow of information, capturing and distilling information, assigning relevancy, and overall, sharing of challenges-to-solutions.

- Some common challenges are likely to be issues of funding to levels of assurance, testing at the component level, and identifying the appropriate testing intersections of design and development.

- The T&E community should try and infuse a scope of abstractions into the process. Levels of abstracting using modeling, for instance, would help to build **confidence levels**. The testing community might want to develop confidence levels for SoS as its measures, versus the risk posture against requirements. String event tests could be used to define confidence levels.
- Need for a feedback loop from users in the field of operations, mission-based, as a means to try collect data from environments that are anticipated and unanticipated.

Jack's table - Where are we, and where are we going?

- The challenges for testing various systems of systems *may not* be solely inherent to the requirements of SoS, so much as they are the limits of the T&E community's ability to test the varieties of SoS.
    - For a start, testers might want to substitute pass/fail for "here's what I know," and "here's what I don't know," based upon the desired capabilities of a SoS.
- Moreover, testers may want to assign probabilities to their results as in "here's what I know," so warfighters can make better assumptions on what to expect.
- While there is need for better definition of capabilities that are sought with a SOS, testers should not be entirely consumed by the external input that follows existing convention. The profession requires "standards of care:" – to develop practices sufficient to meet the challenges of SoS.
- The biggest Unknown is what you don't know about the Knowns –

- How can we test and evaluate, test and evaluation?

Is it “defining” a mission gap?

Readout from World Café session
Chaired by John Thomas, President, INCOSE
ITEA Conference on T&E of SOS
1/27/2012
by
Jack Ring
Facilitator, Table 3

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