

System of Systems Management: A Network Management Approach

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Abstract - *This paper presents a method of applying the International Organization for Standardization (ISO) Network Management Model to the Boardman-Sauser Distinguishing Characteristics of System of Systems (SoS). The ISO model defines five conceptual areas for managing networks: Performance, Configuration, Accounting, Fault, and Security. This model is both a standard and primary means for understanding the major functions of network management.*

The Boardman-Sauser characteristics of Autonomy, Belonging, Connectivity, Diversity, and Emergence are used to recognize a SoS. These characteristics represent the fundamental "building blocks" of SoS management.

In this paper the five functional areas of network management are analyzed and mapped to each of the five "building blocks" of SoS management to create a SoS Operational Management Matrix (SoSOMM). The matrix will serve as a foundation for extracting network management 'best practices' into the realm of SoS management. The proposed method will increase the overall effectiveness of SoS management practices.

Keywords: System of Systems, SoS, Network Management, ISO/IEC 7498, Sustainment Management, FCAPS, DoD 5000.

1 Introduction

System's Management is an intricate topic that combines project, business, and engineering management to handle complex systems that would otherwise exceed the abilities of one single discipline. The merger of these concepts forms a management system that can be as complex as the system being managed. With the current research and practice toward the concept of System of Systems (SoS), defining what a SoS is has proven difficult enough [1]. Thus successfully managing these systems will require a dynamic, structured yet simplified approach.

Since SoS is a relatively new, uncharted concept of designing and managing systems, there is very little

information present in case studies on how to extract best practices. In order to fill this void we propose the use of Network Management concepts in both operating and supporting the SoS. By linking SoS to Network Management practices we can extract proven practices from the network world and apply them to SoS. We will begin by first using a definition of SoS to define the scope of our work. Next, we will show how a SoS can be represented as a net-centric system. Then, we will introduce the concept of Network Management and translate it to the SoS domain. Finally, we will map the SoS defining characteristics and the network management principals to produce a SoS management matrix. We will end our discussion with the application of this concept to sustainment management

2 Boardman-Sauser Distinguishing Characteristics

One of the most challenging activities in SoS management is to recognize a SoS. There have been numerous attempts, yet there is still no universally accepted definition of a SoS [1-5]. We have chosen the Boardman-Sauser Distinguishing Characteristics of SoS [6] because these characteristics are traceable back to the centre of gravity in the arguments as to what constitutes a SoS, as evidenced in the literature [7]. Below is a listing and description of each characteristic.

- **Autonomy** – Autonomy is exercised by constituent systems in order to fulfil the purpose of the SoS.
- **Belonging** – Constituent systems choose to belong on a cost/benefit basis; also in order to cause greater fulfilment of their own purposes, and because of belief in the SoS supra purpose.
- **Connectivity** – Dynamically supplied by constituent systems with every possibility of myriad connections between constituent systems, possibly via a net-

centric architecture, to enhance SoS capability.

- **Diversity** – Increased diversity in SoS capability achieved by released autonomy, committed belonging, and open connectivity.
- **Emergence** – Enhanced by deliberately not being foreseen, though its crucial importance is, and by creating an emergence capability climate, that will support early detection and elimination of bad behaviours.

With these characteristics in mind we must now examine what truly constitutes a SoS. Shenhar [8] was one of the first who described the SoS as a network of systems functioning together to achieve a common purpose. Later, others such as Maier [3] and Lane [9] identified other universally known network-centric systems as examples of collaborative SoSs. (i.e. The Internet, global communication networks, etc.) We will adopt this view and postulate that if SoSs can be benefited by being represented as networks, we can apply network management theory to successfully understand the nature of managing these systems. This will enable us to adopt the best practices of network management to the management of SoS. We must now examine the fundamentals of network management.

3 ISO Network Management Model

The International Organization for Standardization's (ISO) Network Management Framework is a reference model created "...to provide a common basis for the coordinated development of management standards" [10]. It consists of five conceptual areas that (1) define terminology, (2) create structure, and (3) describe activities for the management of net-centric systems. Listed below are the five areas with their definitions and some examples of the functionality encapsulated within each [10].

- **Fault Management (FM)** – Encompasses fault detection, isolation and the correction of abnormal operation of the Open Systems Interconnection Environment (OSIE). Functionality of FM includes:
 - i. Maintain and examine error logs;
 - ii. Accept and act upon error detection notifications;
 - iii. Trace and identify faults;
 - iv. Carry out sequences of diagnostic tests; and
 - v. Correct faults.
- **Configuration Management (CM)** – Identifies, exercises control over, collects data from, and provides data to open systems for the purpose of preparing for, initializing, starting, providing for the

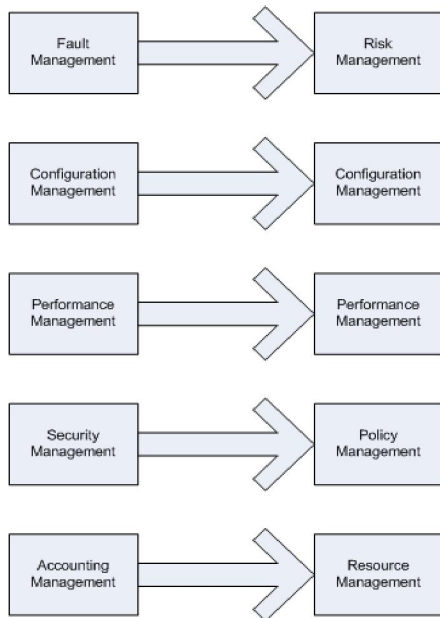
continuous operation of, and terminating interconnection services. Functionality of CM includes:

- i. Setting the parameters that control the routine operation of the open system;
 - ii. Associating names with managed objects and sets of managed objects;
 - iii. Initializing and closing down managed objects,;
 - iv. Collecting information on demand about the current condition of the open system;
 - v. Obtaining announcements of significant changes in the condition of the open system; and
 - vi. Changing the configuration of the open system.
- **Accounting Management (AM)** – Enables charges to be established for the use of resources in the OSIE, and for costs to be identified for the use of those resources. Functionality of AM includes:
 - i. Informing users of costs or resources consumed;
 - ii. Enabling accounting limits to be set and tariff schedules to be associated with the use of resources; and
 - iii. Enabling costs to be combined where multiple resources are invoked to achieve a given communication objective.
 - **Performance Management (PM)** – Enables the behaviour of resources in the OSIE and the effectiveness of communication activities to be evaluated. Functionality of PM includes:
 - i. Gathering statistical data;
 - ii. Maintaining and examining logs of system state histories;
 - iii. Determining system performance under natural and artificial conditions; and
 - iv. Altering system modes of operation for the purpose of conducting performance management activities.
 - **Security Management (SM)** – Support the application of security policies. Functionality of SM includes:
 - i. The creation, deletion, and control of security services and mechanisms;
 - ii. The distribution of security-relevant information; and

- iii. The reporting of security-relevant events.

Together Fault, Configuration, Accounting, Performance, and Security (FCAPS) provide a complete management model for Information Technology (IT) network systems. Bass [11] suggested the application of the ISO network management model to managing net-centric systems. While the definitions above apply to IT network systems they require some modification to be abstracted to apply at the SoS level. We have created the following mappings depicted in Figure 1.

Figure 1: ISO to SoS Conceptual Areas



We define each of the SoS management conceptual areas as follows:

- **Risk Management** – Monitor, identify, asses, analyze, and mitigate risk encountered in the SoS;
- **Configuration Management** – carry out Command and Control, Structural, and Software Management;
- **Performance Management** – monitor and measure performance of individual systems for the overall SoS performance to be maintained at an appropriate level;
- **Policy Management** - provide SoS access to authorized processes and protect SoS from illegal access; and

- **Resource Management** – provide usage information of Systems’ resources in the SoS.

The question that should arise at this point is ‘how does one relate these conceptual areas to a SoS?’. In order to answer this questions one first must ask ‘what is a SoS?’. We have already demonstrated a methodology for identifying a SoS, so what the question really becomes is: ‘Now that we have a way to identify the primary characteristics of a SoS, how do we manage it in such a way as to preserve those characteristics?’. In order to answer this question we have functionally mapped each of the five Boardman-Sausser characteristics with each of the five SoS Management conceptual areas.

4 System of Systems Operational Management Matrix (SoSOMM)

In creating the SoSOMM we considered the question ‘how would X Management affect Y?’. Where X is a management characteristic listed in the top row of the SoSOMM, and Y is a Boardman-Sausser characteristic listed in the first column. It is imperative to consider the whole matrix during assessment of individual cells, i.e. the whole is greater than the sum of the parts [12]. Figure 2 depicts the SoSOMM.

We will now revisit our concept of extracting the best practices of network management. While the SoSOMM itself is a theoretical framework it must be accompanied by solid practical solutions to the principals that fill each cell. As an example we will take the intersection of Configuration Management and Belonging, the matrix offers up the affect of ‘Recognizes Component/System Belonging’. This implies that the use of configuration management within the SoS should allow each system to uniquely recognize itself and others as being part of the SoS. The network management practice here is the use of a hierarchical managed object identification system, such as a spanning tree and/or Management Information Base. Other best practices that can be extracted include (but not limited to)[13, 14]:

- Information Modelling;
- Management Protocols;
- Agent Based Modelling;
- Event Handling;
- Performance Evaluating;
- Topology Mapping;
- Message Passing.

FCAPS has been used to successfully manage and reduce complexity in IT systems [11, 13-16]. The SoSOMM in conjunction with the extracted best practices will provide the same for SoS Management.

Figure 2. SoS Operational Management Matrix

| | Risk Management | Configuration Management | Performance Management | Policy Management | Resource Management |
|---------------------|---|--|--|--|---|
| Autonomy | Preserves autonomous capabilities | Governs autonomous behavior | Optimizes component system performance in order to meet SoS capabilities | Ensures security of component systems | Provides information on autonomous resources |
| Belonging | Provides environmental perspective | Recognizes component/system belonging | Provides cost/benefit optimization | Restricts/allows component systems access to the SoS | Provides information on component system function in SoS. |
| Connectivity | Maintains acceptable integration | Establishes and maintains consistency in integration | Optimizes to maximum capability | Protects from unauthorized integration | Resource tracking |
| Diversity | Evaluates diverse activities | Governance of diverse behavior | Optimizes diverse activities | Restricts/allows diverse behavior | Provides an inventory on diverse resources |
| Emergence | Verifies and validates achievement of new behaviors | Shapes and bounds emergent behavior | Allows optimum path of emergence | Polices "bad" emergent behaviors | Tracks emergent capabilities |

5 Conclusions

By making the connection between SoS characteristics and the conceptual areas of network management we have created a framework for extracting and applying the best practices of network management. The SoSOMM is the first step toward a simple yet structured and dynamic approach to SoS management. The research suggests that it is feasible to apply network management concepts to a SoS in order to both reduce the complexity of management and increase the operational sustainability.

6 Future Research

The SoSOMM has been developed through the use of theoretical research; practical applications demand the following future work.

- Refinement of cell content
- Use SoSOMM to evaluate a real-world SoS (possibly the Internet)
- What network management practices apply to SoS, what ones do not?

A practical tool for SoS management is a future objective of the authors of this paper.

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