

Boundary Objects as a Framework to Understand the Role of Systems Integrators

Allan Fong, Jayakanth Srinivasan, Ricardo Valerdi
Massachusetts Institute of Technology, Lean Aerospace Initiative
77 Massachusetts Avenue, Building 41, Room 205
Cambridge, MA 02139-4307
{afong05, jksrini, rvalerdi}@mit.edu

Abstract

The US military is facing challenges to develop the capabilities necessary to effectively operate in new war environments. As a result, the military is seeking to partner with industry members and leverage both government and industry knowledge to develop System of Systems that can provide the desired capabilities by integrating legacy systems with new technologies. These large scale engineering projects require system integrators that can manage not only the technical interfaces but also the organizational ones. This paper proposes a boundary object framework that can assist in understanding the role of these systems integrators by demonstrating that a Boundary Object Characterization Model can be used to observe changes in organizational interfaces. This model does so by monitoring the objects and artifacts used at the interfaces.

Introduction

The military is facing new challenges as a result of a tightening spending budget and the need to acquire novel capabilities to operate in new war environments. This requires integrating legacy systems with developing technologies in what is generally defined to be a System of Systems (SoS). SoS is used to

describe both technical and organizational systems. When dealing with the integration of large systems, it is difficult to separate the organizational systems from the technical systems. The interfaces of organizational systems, i.e. the transfer of documentation or requirements from one group to another, is just as important as the interfaces of technical systems, i.e. the exchange of bits, energies, and stresses. However, the military does not have the knowledge base to integrate such systems anymore due to the enormous complexity of these systems and lack of human resources in the military. As a result, the military is contracting Lead Systems Integrators (LSI) as a way to partner with industry members and leverage the technical and managerial knowledge of industry organizations.

Finding a way to understand what systems integrators do is operationally beneficial and can be used for contracting purposes. However, the role and value of the LSI is not well-defined and difficult to measure in part because the roles, responsibilities and boundaries of different stakeholders (customers, integrators, contractors, etc.) involved in a SoS are often blurry. As a result, it is crucial to look at the interfaces within the different constituents of a SoS in order to better define boundaries and assess inter-organizational interactions.

Interfaces amongst organizations occur when there is some kind of formal or informal interaction. These interfaces typically involve the use of some object or artifact that is exchanged between the different stakeholders. These objects have been referred to in past literature as boundary objects. This paper uses three boundary object model to better understand these interfaces and the role of a lead systems integrator.

Boundary Objects Literature

Boundary objects are objects that are flexible enough to adapt to local needs and the constraints of the stakeholders employing them, yet specific enough to maintain a common identity across different interpretations. These objects have different meanings in different communities of practice, but their structures are common enough to more than one community, making them recognizable by a means of translation and interpretation (Star and Griesemer 1989). Objects are generally defined as the artifacts that a person or community works with (Carlile 2002). These objects can be physical objects, such as architecture framework print outs, or electronic objects, such as e-mail. In addition, they carry information, which can be explicit or implicit. For example, explicit information can be directly represented, such as on a blueprint or instruction manual, or information can be implied, such as the imbedded information in a product or picture. Boundary objects have been applied to many areas of research. The table below highlights some literature that applied boundary objects to study the interactions between different communities of practices in various fields

| Field | Organization | Boundary object |
|----------------------------------------------|------------------------------------------|-------------------------------------------------|
| Social science (Star and Griesemer 1989) | Museum of zoology | Diagrams California map Collecting method |
| Design engineering (Henderson 1991) | Engineering firm | Sketches Drawings CAD |
| Product development (Carlile 2002) | Automobile design and manufacturing firm | Drawings Automobile parts Schedule |
| Software development (Gunaratne et al. 2004) | R&D facility | Storyboard Prototype |
| Service (Ackerman and Halverson 1999) | Telephone hotline group | Written records |

Objects become boundary objects when they are used at the interface of different communities of practice. An object that is only personally used, such as an electronic paper stored on ones computer, is not a boundary object because it is not used to bridge different communities of practices together. However, if that paper is submitted to a conference, then it becomes a boundary object.

A community of practice is a group across which sense-making, understanding and knowledge is shared. More specifically, a community of practice has a shared understanding of what the community does, of how to do it, and of how it relates to other communities and their practices. A community of practice will develop the same world view or mental model (Brown and Duguid 1998). These communities of practices have been also referred to as social circles, stakeholders, organizations, etc. Boundary objects essentially exist and are used at the interfaces between these communities of practices. The figure below is a representation of the purpose of boundary objects. If designed and used properly, they

Table 1: Boundary object literature

can connect together what were once separate communities. The boundary object bridges allow the communities avenues to communicate, coordinate and collaborate. This paper categorizes organizations as communities of practices and focuses on the use of boundary objects at these community interfaces.

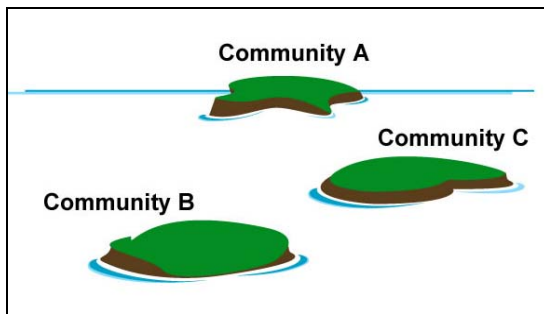


Figure 1. Separate island communities

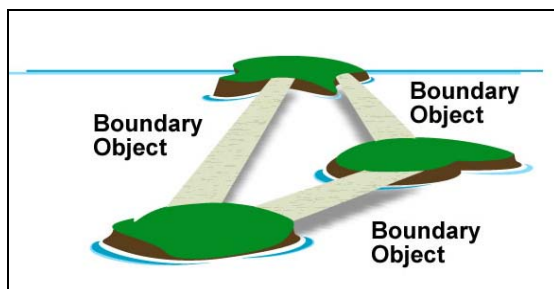


Figure 2. Boundary objects as bridges

Furthermore, boundary objects carry information and context that can be used to translate, transfer and transform knowledge between communities of practice (Carlile 2004). The design and use of boundary objects are especially important when working between communities that are geographically separated, but should not replace face-to-face interactions. How well geographically separated communities work together is correlated to how well they share information and knowledge at the interfaces (Sapsed and Salter 2004). Furthermore, these objects can also be dynamic. They can be changed and manipulated to carry more information or context. For example, a user can layer a boundary object, such as a requirements

document, by highlighting certain phrases, writing comments in the margins or crossing out certain parts (Swartz 2004). Each style of marking adds an additional layer to the object. As a result, the evolutionary characteristic of a boundary object and its ability to carry information and context, allow different communities to interface (communicate, coordinate or collaborate) with each other.

The following sections further explain the boundary object concepts using three models. The mental model is used to understand the different community interpretations of a boundary object when it is passed between different communities. The bridge model is then described to understand the need for boundary objects and the environment in which they will function. Lastly, the Characterization Model categorizes boundary object attributes.

Boundary Object Mental Model

The effectiveness of a boundary object is directly related to how it is decontextualized and recontextualized between different communities. For example, a technical drawing can mean different things to a designer and a manufacturer. The designer might look at the technical drawing and envision how the component fits and functions with other components as an end product. The manufacturer might look at the technical drawing and think about the machining steps necessary to manufacture the component.

This model helps communities understand how the boundary object is interpreted by other communities. It increases understanding, situational awareness and is very important for the system integrator. The figure below is a depiction of the different mental models during a very simplified design/manufacturing process.

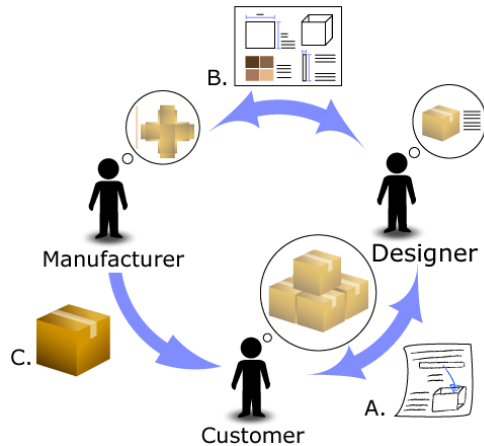


Figure 3. Boundary object mental model

(A) The process starts between the customer and the designer. The customer desires a specific component and has a mental model of what that component is going to be used for. The customer needs to translate his mental model to the designer. He needs to decontextualize his idea into a transferable form for the designer. To accomplish this, a boundary object, in this case a sketch and description of the component, is created and used by the two parties. When the designer looks at the drawing, he will translate it to a specific mental model focusing more on the technical properties of the component rather than its eventual use.

(B) The designer now needs to translate his model to the manufacturer. To do this, the manufacturer and designer have to work together to create a boundary object, a technical drawing, that both parties can understand. The object contains the decontextualized knowledge from the designer which can be recontextualized by the manufacturer. Nevertheless, when a manufacturer looks at the drawing, he will focus on the assembly aspect of the part.

(C) Once the component is manufactured, it becomes a boundary object. The arrow is unidirectional because, in this case, the customer does not provide feedback to the manufacturer if changes are needed. If the

customer is not satisfied, he will need to talk to the designer again. Although this is a simple model, it highlights a problem area that exists between the manufacturer and customer. The knowledge decontextualized into the final product will not be successfully recontextualized by the customer if the part is not exactly what the customer desires.

Boundary Object Bridge Model

One role of a boundary object is to bridge the gap between different communities. A boundary object, a bridge, must be developed with input from all of the sides. Logically, the more communities that the boundary object needs to connect, the more complicated the boundary object becomes. It is important for there to be effective communication between all of the parties involved with the development of a boundary object.

The types of bridges used will be specific to the gaps they need to connect. The solution must match the need. Sometimes the best solutions are the simple and cheapest ones. Other times, expensive bridges must be built.

The figure below is a cartoon of the bridge model concept.

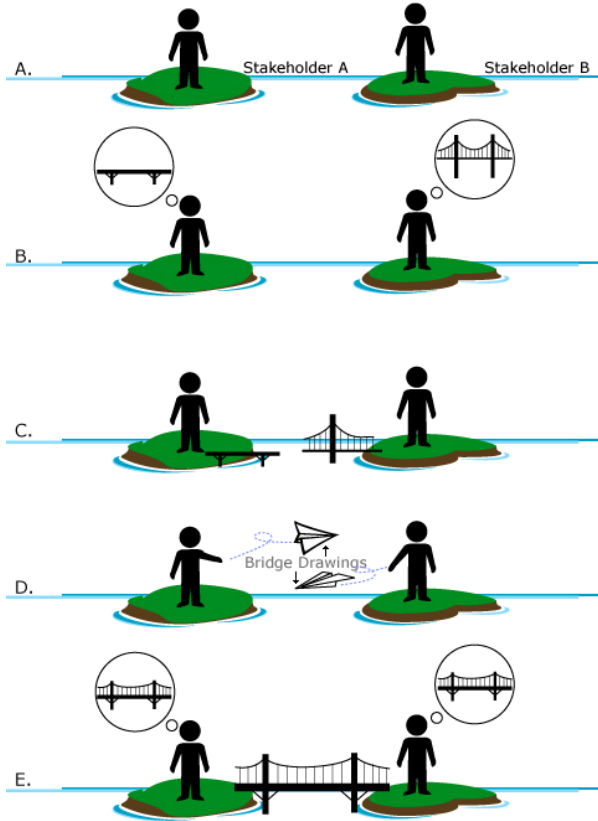


Figure 4. Boundary object bridge model

(A) Community A and Community B are on two different islands separated by a gap. (B) They both want to construct a bridge to close the gap between them but without communication they develop different solutions to the same problem. (C) This lack of communication leads to both sides constructing different bridges. Problems will occur when they try to connect the two bridges. This will lead to rework and wasted resources. However, if both groups start with a common vision they will be able to construct a successful bridge between them. (D) The bridge drawings sent back and forth between the stakeholders are the boundary object that connects both parties. (E) A successful bridge must include the input and be developed by both stakeholders. Once the bridge is built, the bridge also becomes a boundary object.

Boundary Object Characterizations

This next sections aims to characterize boundary objects using previous and current research. This paper will discuss six different attributes for boundary objects: type, functionality, utility, information, context and previous relationship.

Type. Boundary objects will be distinguished into two types of objects: virtual and physical. Virtual boundary objects are those that exist in bytes and bits. They are stored in computers, databases, palm pilots, etc and are transferred electronically. Examples of virtual boundary objects are e-mails, websites, and electronic databases. Physical boundary objects are objects that you can hold in your hands and physically manipulate, such as by highlighting, crossing-out and so on. Physical boundary objects are usually transferred from people to people such as being sent through the post office. Examples of physical boundary objects are hardcopies of design documents and aircraft clay prototype models.

Functionality. Star and Griesemer categorized boundary objects into four functional categories: repositories, ideal type, coincident boundaries, and standardized forms. Repositories are ordered collection of objects such as a library or database. Ideal types are abstractions from different domains and may be open to a fairly broad spectrum of interpretation. Ideal types include diagrams, drawings, and clay models. Coincident boundaries are common objects which have the same boundaries but different internal contents (Star and Griesemer 1989). An office building is an example of a coincident boundary because representatives from different organizations can all work within the same physical boundary. Lastly, standardized forms are objects that provide different communities with a common way to communicate. Standardized forms include

forms for clearance procedures and proposal submissions. This paper will apply this characterization to boundary objects used in SoS.

Utility. The utility of the boundary object is how many times the object is used. It is possible to have a very useful boundary object that does not serve its purpose because it is not used. Example of underused boundary objects are lesson learned databases. These databases store a vast amount of information but often times are rarely accessed after they have been created.

Information. Information representation is very important to how boundary objects are used. In many cases, objects carry vague or misleading information. Objects that use ambiguous terms, such as “very much” or “too little,” can lead to confusion between communities of practices. Furthermore, an object can include different amounts and types of information. For example, the financial record of a company can be presented in a large excel chart with all of the spending and earning numbers or it can be presented in a word document that summarizes all the numbers.

Context. The context of the boundary object describes how well it addresses the different social contexts and mental models of the user groups. The differences in social contexts and mental models of different communities lead to understanding gaps, which were addressed as attributes of the coordination and collaboration interface. Some communities may be able to understand each other better than others. Their mental models are more aligned and, in these cases, it may be easier to bridge the understanding gaps.

Previous Relationship. The manner in which boundary objects are used also depends on the previous relationships of the stakeholders involved in the interaction. Previous partnerships and contractual agreements are examples of previous

relationships that can affect the trust between the stakeholders. Using the boundary object implies there is some level of trust between the sender and receiver. Trusting what is represented in the object and trusting the organization that sent it is essential for collaborative interfaces. If the object clearly represents all the information needed between two stakeholders, but if one stakeholder doesn't trust the other stakeholder, then the former user will probably be hesitant to use the information.

Boundary Object Characterization Model

The Boundary Object Characterization Model applies previous boundary object literature to characterize boundary objects based on its type, functionality, utility, information, context, and previous relationships between the two user groups, as shown in the following figure. This paper proposes this model as a novel method to characterize the boundary objects used at a specific interface. By considering the objects used at current interfaces, one can create new interfaces or modify existing ones to create more capabilities in the system.

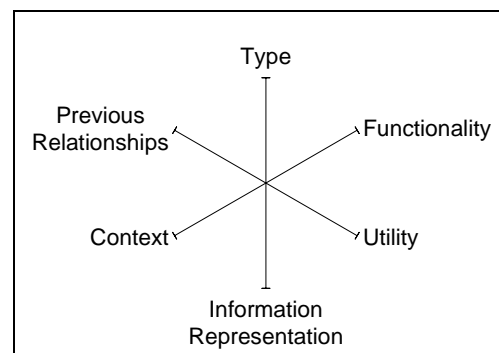
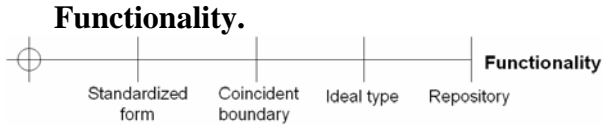
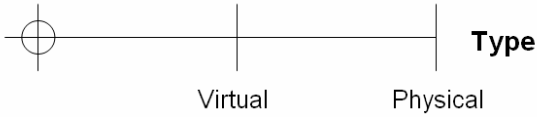


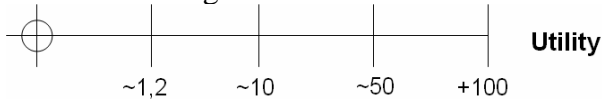
Figure 5. Boundary object attributes

The axes for the boundary object attributes are described below.

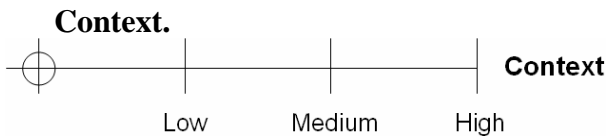
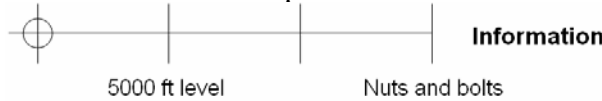
Type.



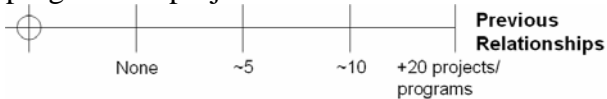
Utility. This is the amount of times the object has been used to aid in the interaction between two organizations.



Information Representation. This is the level at which information is represented from very high conceptual level (the 5000ft level) to the nuts and bolts specifics.



Previous Relationship. This can range anywhere from no previous relationship to past partnerships on more than 20 different programs or projects.



The Boundary Object Characterization Model takes a different approach to understanding organizational interfaces by giving a physical meaning to several variables necessary to understand organizational interactions. Variables such as understanding and trust become embodied in the objects used. Users of this framework can understand organizational interfaces more quantitatively. Although the Boundary Object Characterization Model is based largely from

past literature involving interactions within an organization, this research aims to take the understanding of boundary objects within an organization and apply it to interorganizational interfaces through the case study. Furthermore, this framework will be a useful tool for systems integrators in understanding and diagnosing organizational interfaces failures.

Model Application

This model analyzes organizational interfaces by characterizing the objects used at these interfaces. The example below is of how this model can be applied to organizational interfaces between an LSI and a contractor that have never worked together before.

First the LSI posts general information about an upcoming program on their website. This is a virtual boundary object and is used a few times because the information on the website is still general and high level. However, the website provides a lot of context as for the reason of the program, who is involved, etc.

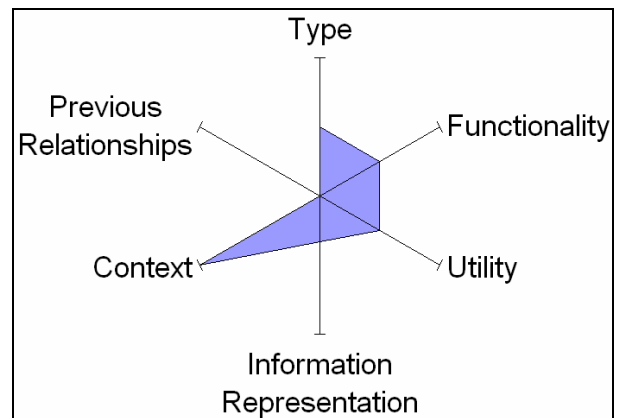


Figure 6. Description of website boundary object

As the LSI receives more requirements and directions from the customer, they will solicit proposals for companies who are

interested. This request for proposals is also done electronically in a standard format. The request will carry a lot of context and more information than just the website.

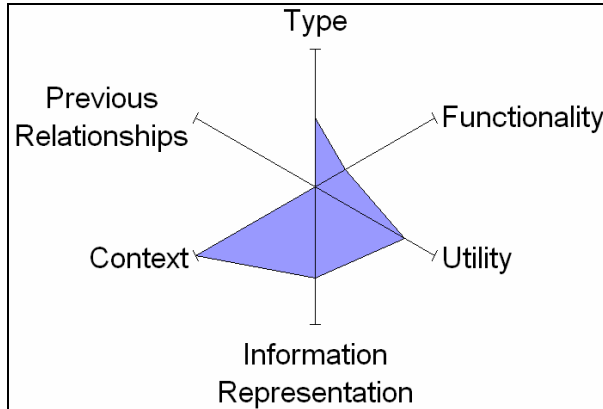


Figure 7. Description of proposal object

After the contractor is picked, they will have to provide bi-weekly presentation updates. These presentations are high level and use PowerPoint. The PowerPoint slides are used only once and do not carry a lot of context because the context is communicated verbally.

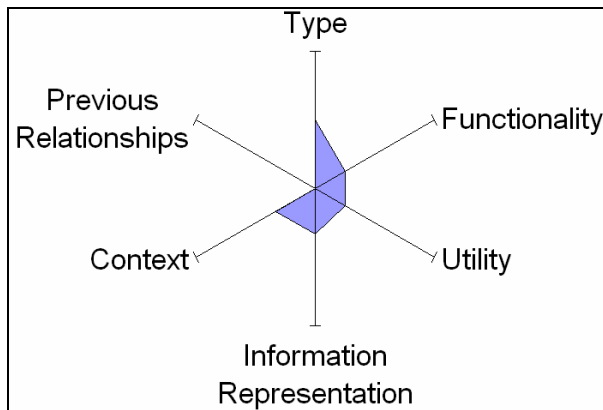


Figure 8. Description of presentation object

Lastly, a physical prototype model is used between the contractor and LSI. There is a lot of information imbedded in the model but does not carry much context.

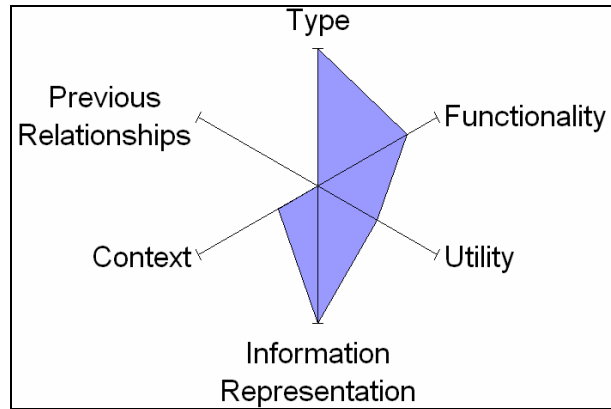


Figure 9. Description of prototype object

Although there are a lot of interfaces besides the ones mentioned above, this example is used to show that this model can be used to capture the type of interface between organizations. This example also shows that boundary objects change as relationships and interfaces between organizations evolve. The evolution of boundary objects can assist in understanding organizational system dynamics. A further expansion of this concept will be included in following papers.

Implications for System Integrators

The most value or leverage in constructing a SoS is at the interfaces (Maier 1998) and it is at these interfaces that the significance of boundary objects is realized. The value of a boundary object depends on how successful it can be used to decontextualize knowledge on one side of a boundary and recontextualize it on the other side. As a result, the role of a systems integrator is, as the name implies, to integrate various systems together by managing the interfaces. Naturally, the systems integrator will care about how the boundary objects at these interfaces are used to integrate the information and knowledge amongst the different communities of practice.

In a SoS with no integrator, the different organizations can be thought of as unconnected islands. The figure below further

expands the previous figure of the bridged communities. This is similar to the bridge model previously described. Before the bridge boundary object is constructed, the different communities will have to work together or else they might end up with different bridge designs incapable of interfacing.

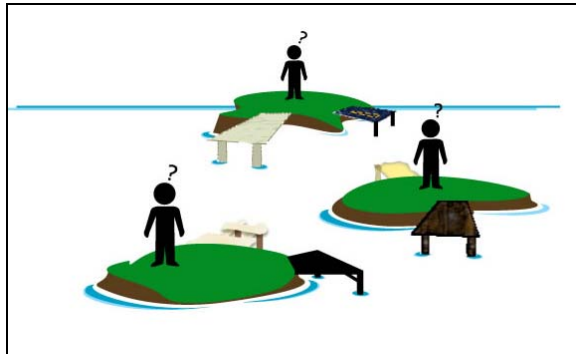


Figure 10. Communities with incompatible interfaces

The systems integrator needs to work within all the communities and become the vital link that connects them. For example, the systems integrator has to make sure everyone is using the same units and compatible CAD software when designing and building their parts of the bridge. The bridge drawings and e-mails sent back and forth between the different communities are boundary objects used for collaboration purposes.

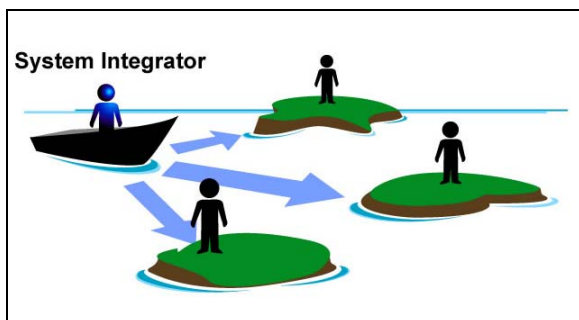


Figure 11. Involvement of a system integrator

By forming successful collaborative interfaces, the different communities will be able to design and build useful bridges. The bridges are another example of boundary objects that can allow more people, resources and information to flow between the communities resulting in more collaboration.

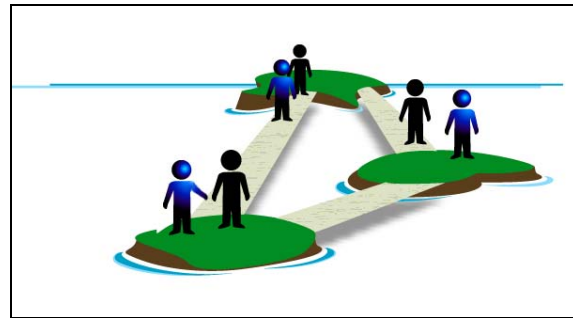


Figure 12. Increase collaboration and value

A systems integrator needs to cultivate, develop, and maintain an environment in which the components of the system can develop, grow, and evolve. This includes providing a focal point for implementing proven best practices across the system and leveraging the work that is being done by other components in the system in a highly coordinated manner (Spurlock 2005) (Gupta 2003). The system integrator must also develop boundary objects and maintain the environment in which these objects operate. In the previous bridge example, the system integrator has to make sure that the different communities can easily exchange information with each other when it is required. Furthermore, the integrator must create system awareness amongst the organizations by ensuring that boundary objects are used effectively for communication, coordination and collaboration purposes. Going back to the bridge example, before the initial construction of the bridge began, the system integrator must make sure all the communities can understand the information they receive from each other. For example, if each community spoke a different language, the system

integrator must provide each community some method of translating each other's language. The systems integrator must be able to address failures in communication, coordination and collaboration between different organizations. The section below further elaborates on types of interfaces and their associated failures.

Certain types of boundary objects will be more effective in some environments as compared to others. Boundary objects can be used to measure the fluidity and flexibility of different constituent systems.

Boundary object research highlights the human aspect of interfacing within System of Systems. Social integration is as important as technical integration.

This theory provides research opportunities in several areas. Further development of the boundary object framework can provide a tool to monitor and measure the integration of different System of Systems. The need for this development and similar research has become increasingly apparent as more and more System of Systems are being developed.

Conclusion

The interfaces within a System of Systems are where the benefits of a SoS come from. However, integrating and interfacing different components of SoS is a difficult task, especially for the military. As a result, the military has contracted out the role of the Lead Systems Integrator to do the SoS integration. Although this role is important, it is not well defined especially when it comes to metrics. This paper provides a boundary object model to analyze the role of the SoS by focusing on how stakeholders in a SoS interface.

There is much work that can be done in this field of research. This paper will hopefully open up the door to a new way of thinking when valuing the role of system integrators.

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the Enterprise Integration enabled by IT cluster, focusing on IT Architectures and Lean Software Development. JK has an undergraduate degree in Computer Engineering and graduate degrees in Avionics and Aeronautics and Astronautics respectively.

Biography

Allan Fong is a graduate student at Massachusetts Institute of Technology in the Department of Aeronautics and Astronautics engineering. His research and his studies are funded by Lean Aerospace Initiative. He will be completing a Masters of Science by May 2007 and is intending to pursue a doctoral degree. Allan graduated from Columbia University in 2005 with a bachelor's degree in mechanical engineering.

Ricardo Valerdi is a Research Associate with the Lean Aerospace Initiative at MIT. He is currently the research lead for the Enterprise Cost and Metrics cluster. Ricardo received his doctoral degree in systems engineering from USC in 2005, where he created for the COSYSMO model for systems engineering cost estimation.

Jayakanth "JK" Srinivasan is a Research Associate with the Lean Aerospace Initiative at MIT. He is currently the research lead for