DEVELOPING A BOUNDARY OBJECT MODEL TO ANALYZE COMMUNICATION INTERFACES: APPLICATIONS FOR SYSTEM INTEGRATORS

by

Allan Fong

B.S. Mechanical Engineering – Columbia University, 2005

Submitted to the Department of Aeronautics and Astronautics in Partial Fulfillment of the Requirements for the Degree of Master of Science in

AERONAUTICS AND ASTRONAUTICS

at the

Massachusetts Institute of Technology

August 2007
[September 2007]

Signature of Author..
Department of Aeronautics and Astronautics
August 10, 2007

Certified by..
Ricardo Valerdi
Research Associate
Thesis Supervisor

Certified by..
Deborah J. Nightingale
Professor of Aeronautics and Astronautics
Academic Supervisor

Accepted by..
New Chair David Darmofal on behalf of
Jaime Peraire
Professor of Aeronautics and Astronautics
Chair, Committee on Graduate Students

DEVELOPING A BOUNDARY OBJECT MODEL TO ANALYZE COMMUNICATION INTERFACES: APPLICATIONS FOR SYSTEM INTEGRATORS

by

Allan Fong

Submitted to the Department of Aeronautics and Astronautics on August 10, 2007 in partial fulfillment of the requirements for the Degree of Master of Science in Aeronautics and Astronautics.

Abstract

Physical information is transferred between technical systems through wires, beams, and other physical attributes, while more intangible information is typically transferred between communities of people through artifacts such as documents, e-mails, etc. This research attempts to characterize these communication interfaces better by analyzing the use of artifacts at these interfaces by means of a boundary object attribute model. Boundary objects, the metric of analysis of this thesis, are artifacts used to bridge information and knowledge gaps between different communities of practice. The US Army's Future Combat System (FCS) was chosen as a case study primarily because of its complex programmatic characteristics. The information gathered in the FCS case study was combined with knowledge from previous boundary object literature to generate an attributes model.

Once developed, the boundary object attributes model was validated on the US Air Force Transformational Communications Satellite System (TSAT) program focusing specifically on the TSAT Mission Operations System (TMOS) segment of the program. Data were collected on the frequency and type of resources used to understand information and the dependencies that individuals have with each other for documented information. Furthermore, five communication artifacts were critiqued for their effectiveness as boundary objects. Statistical tests were conducted to highlight trends in resource dependencies and attributes common in effective boundary objects. An implication of this research is that the most important attributes for a boundary object are inclusivity, traceability, and synchronization. This research also found that people generally tend to rely much more on other people for information than artifacts. This introduces problems of exhausting valuable human resources and creating unnecessary bottlenecks. A second implication of this research is that spending the extra time and effort to design artifacts with high inclusivity and freshness will add significant value to the overall system. In addition, a third implication of this research is that having the right boundary objects alone is not enough for effective collaborative interfaces. A fourth implication of this research is that designing a boundary object whose form follows its function is critical for its effectiveness. These suggestions can provide relief to a program highly taxing to its human resources and reduce transaction costs of the overall system. Furthermore, this model may be extended for the purpose of determining the roles and responsibilities of system integrators.

Thesis Supervisors:
Deborah J. Nightingale, Professor of Aeronautics and Astronautics
Ricardo Valerdi, Research Associate

Acknowledgements

Growing up I always wanted to be an astronaut and to explore the many unknowns in the universe. Coming to MIT, I was offered a research assistant position at Lean Aerospace Initiative (LAI). I found LAI to be an excellent place to apply and merge my knowledge and interests in engineering, psychology, economics, and policy. I quickly realized that the issues of the world extend beyond superior technological solutions. Understanding this opened my eyes to whole new research fields. With the help and guidance of my advisors I was able to scope down my research interests into this master's thesis. The process was not easy, but fortunately many people were there to help me along the way.

I am greatly indebted to Dr. Ricardo Valerdi for all the times he has helped me throughout my master's program, from understanding the subtleties of networking to reserving cars. Dr. Ricardo Valerdi has become much more than an advisor to me. He has become my tennis partner, role model, friend, and mentor. I am very grateful for the patience and understanding he has shown me and his desire to know who I am as a person. Not only has he helped me shape my research, but the skills he has taught me and advice he has given have shaped me as a person. I look forward to further strengthening our relationship in the future.

Jayakanth Srinivasan (JK) and my academic advisor, Professor Deborah Nightingale, have also been wonderful role models for me. JK always seems to have a calm air about him when listening to my concerns or problems. His "been there, done that" advice has proven very useful. Professor Deborah Nightingale is also someone I admire. Her ability to relate to and understand students is always amazing. She not only cares about my research but about me as a person, what I plan on doing after graduation, etc. I thank her for her wealth of wisdom and encouragement.

This research would not have been possible without the financial support and enthusiasm from The Aerospace Corporation. I thank Richard Adams and Bonnie Troupe in particular for their interest and commitment to this research. The primary research case study all started when I connected with Richard Adams at the LAI 2006 Plenary. Since then he has been a constant supporter of this research, providing valuable insight, suggestions, and direction for me. Bonnie Troupe has also been an amazing and wonderful person to work with. Her enthusiasm and desire to change the status quo have been very encouraging. Both Richard's and Bonnie's real-world experience have provided tremendous insight to this research.

Dr. George Roth, Professor Paul Carlile, and Don Greer have significantly helped me understand and shape my research topic. I would like to thank them for their time and all the feedback, suggestions, and guidance they provided me.

My MIT experience might not have been possible with the initial funding support at LAI. I am greatly appreciative for the opportunity to come on-board as a research assistant and work with so many great people. I especially want to thank Tara Eisner whose continuous smile and willingness to help made transitioning and working at LAI very enjoyable. I would also like to thank all the other LAI faculty, staff, and students for their help and support.

My experience at MIT would not have been what it was without all the wonderful friends I have made here. There are so many people who have shaped and influenced who I am as a person. Graduate school has definitely been very trying at times but I have always found encouragement and strength in my fellowship and friends. Thank you to my bible study and fellowship for all the prayers and encouragement. They have kept my heart and mind focused on God even through the toughest of storms. Thank you to all the friends I made in Sidney Pacific as an officer. Thank you MIT Sport TKD for providing a good release for my stress.

To Jeanette Tse: Thank you for standing by me and walking with me even though I know you are very busy with your medical school work. I cannot thank you enough for all the hours you spent listening to me rehearse my presentations or proofreading my papers. I appreciate the fact that you are able to tell me when I need to take a break or when I need to stop over-committing myself. Thank you for your love and your patience.

To my family: Thank you Mom and Dad for your words of wisdom to me. Although you trust me now to make my own decisions, I will always turn to you for advice and guidance. Diana: Thank you first for all the graphics! I know that you said these graphics are not your best work, but they are pretty amazing to me. Thank you also for acting as the bridge between Dad and me during difficult times. Edward: Thank you for your words of wisdom and advice after having been through this master's program yourself. Thank you for suggesting I take 18.085. It was an amazing class! Thank you for also being a big brother and role model for me, and for being someone I can look up to and respect.

Above all, I thank God for His constant and never-ending provision and love.

> "He gives strength to the weary and increases the power of the weak. Even youths grow tired and weary, and young men stumble and fall; but those who hope in the Lord will renew their strength. They will soar on wings like eagles; they will run and not grow weary, they will walk and not be faint." Isaiah 40: 29-31

Table of Content

Abstract 3
Acknowledgements 5
Table of Content 7
List of Figures 9
List of Tables 10
1 Introduction 11
1.1 Definitions 14
1.2 Methods 15
1.3 Chapter overview 16
2 Evolving Role of the Lead System Integrator for System of Systems 19
2.1 System of Systems 19
2.2 Lead System Integrators 21
3 Problem Statement 26
4 Communication, Coordination, and Collaboration 28
4.1 Communication 28
4.2 Coordination 30
4.3 Collaboration 32
4.4 Interface characterization model 33
5 Boundary Objects 36
5.1 Boundary object literature 36
5.2 Communities of practice 39
5.3 Mental model 41
5.4 Boundary object attributes model 43
6 Future Combat System Case Study 50
6.1 Background 50
6.2 Approach 51
6.3 Observations and discussion 52
6.4 Conclusion 55
7 TMOS Case Study 57
7.1 Background 57
7.2 Motivation 58
7.3 Approach 58
7.3.1 Social interaction survey 60
7.3.2 Organizational interfaces 61
7.3.3 Understanding information 65
7.3.4 Boundary object attributes 66

7.3.5 Statistical analysis 67
8 TMOS Results 72
8.1 Social interaction survey 72
8.2 Organizational interfaces 73
8.3 Understanding information 76
8.4 Boundary object attributes 80
8.4.1 Artifacts 80
8.4.2 Attributes 87
8.4.3 Importance 91
9 Discussion 92
9.1 Understanding information 92
9.1.1 Dependencies on artifacts and people 95
9.2 Organization interfaces 97
9.3 Analysis of artifacts 99
9.4 Attribute discussion 102
9.5 Implications 104
9.5.1 E-mail example 108
9.5.2 Modifying objects 108
9.6 Case study conclusion 110
10 Future Research and Conclusion 112
10.1 System integrators 112
10.2 Future research 114
10.3 Conclusion 115
Biography 118
Appendix 119
Appendix A: LSI definitions 119
Appendix B: FCS case study survey 121
Appendix C: TMOS social network survey 123
Appendix D: TMOS case study survey for software engineers 125
Bibliography 131

List of Figures

Figure 1: Summary of research methods 15
Figure 2: Interface characterization model 35
Figure 3: Separate island communities 40
Figure 4: Boundary objects as bridges 40
Figure 5: Boundary object mental model 42
Figure 6: Communication interface results 74
Figure 7: Coordination interface results 74
Figure 8: Collaborative interface results 75
Figure 9: Summation of ranks across subjects for A020, A022 and ICD 77
Figure 10: Resources subjects typically turn to for information 79
Figure 11: Attribute scores for Comment Matrix, Org. Chart and Database 82
Figure 12: Attribute scores for A022 and ICD 83
Figure 13: Average freshness responses 84
Figure 14: Estimated marginal means for calculated artifact freshness 84
Figure 15: Estimated marginal means for frequency of interaction 86
Figure 16: Estimated marginal means of calculated inclusivity 86
Figure 17: Estimated marginal means for granularity, accessibility and malleability 88
Figure 18: Estimated marginal means for synchronization, importance and understandability 89
Figure 19: Estimated marginal means for traceability, freshness and inclusivity 90
Figure 20: Ineffective boundary object case scenario 94
Figure 21: Effective boundary object case scenario 94
Figure 22: Estimated level of usage for Government and FFRDC subjects 95
Figure 23: Human resources used by subjects arranged according to community 96

List of Tables

Table 1: LSI deifinitions and roles 22
Table 2: Summary of communication interfaces 29
Table 3: Summary of coordination interfaces 31
Table 4: Summary of collaboration interfaces 33
Table 5: Boundary object literature 37
Table 6: Attributes discussed in various boundary object papers 49
Table 7: Interface characterization 63
Table 8: Artifact descriptions 65
Table 9: Resource ranking 66
Table 10: Average interface responses characterized by community 76
Table 11: Mann-Whitney test results 77
Table 12: Friedman test results 78
Table 13: Multiple pairwise test results 79
Table 14: Levene's test results 81
Table 15: Levene's test results for freshness and frequency 85
Table 16: Summary of attribute scores for the different boundary objects 87
Table 17: Definition of acronyms in Table 16 87

1 Introduction

The U.S. military is facing a plethora of challenges as a result of tightening procurement budgets and the need to acquire new capabilities to operate in modern war environments. This requires integrating legacy systems with developing technologies in what is loosely defined to be a System of Systems (SoS). For these SoSs, the interfaces of organizational constituents (i.e. the transfer of documentation or requirements from one group to another) is just as important, if not more important than the interfaces of technical systems (i.e. the exchange of bits, energies, and stresses). Integrating these systems has been very difficult, particularly for the military, which is struggling to retain the necessary knowledge base to perform such tasks. As a result, for some large programs, the military is using the concept of a Lead Systems Integrator (LSI) as a way to partner with industry members and leverage the technical and managerial knowledge of industry organizations. It is becoming increasingly apparent that the role of the LSI is more managerial than technical (Bar-Yam and Kuras 2003; Gupta 2003; Laird 2003). Finding a way to understand the processes and mediums with which different organizational and communities collaborate is crucial in understanding the role and responsibilities of the LSI and other system integrators. Such understanding is beneficial operationally and contractually.

It is essential to look at the interfaces between the different constituents of a SoS. Eberhardt Rechtin states that the greatest leverage in system architecting is at the interfaces. These interfaces usually take on the form of some communication artifact that exists between different organizations or communities of practices. These artifacts have been referred to in past literature as boundary objects (Star and Griesemer 1989; Carlile and Schoonhoven 2002). Generally speaking, boundary objects are artifacts that exist between different communities of practice or social circles, which are flexible enough to adapt to local needs, yet specific enough to maintain a common identity across different interpretations (Star and Griesemer 1989).

This research proposes a boundary object attribute framework to understand communication interfaces between different communities of practices. A case study was first conducted to understand the communication interactions between various organizations in the US Army's Future Combat System. The observations and discussions from this study allowed the development and refinement of the boundary object attributes model. This model was then applied to study the communication interactions in the Transformational Communications Satellite System (TSAT) Mission Operations System (TMOS) program. Data from this case study were used to determine disconnects in the program, resource dependencies, and how different communication mechanisms were used to exchange knowledge and information. It is determined that artifacts with high traceability, inclusivity, and freshness perform more effectively as boundary objects at the collaborative level. This suggests that spending the extra time and resources to maintain these attributes may be a worthy investment. Moreover, artifacts, whose forms follow their general function, tend to be used more as effective boundary objects. This research demonstrates that a boundary object attribute model can be used to analyze communication interactions and the effectiveness of boundary objects. The results from this research also suggest that the current usage of documents in the case study may not be the most effective way to use the resources. Although a number of past research articles have looked at documents at boundary objects (Star and Griesemer 1989; Swarts 2004), this research has highlighted some of the difficulties in considering documents as effective boundary objects.

Furthermore, the applications of using boundary objects to analyze the roles and responsibilities of systems integrators are discussed. The role of systems integrators involves tasks such as ensuring communication and collaboration amongst partnering organizations. To understand the role of these system integrators, or Lead Systems Integrators, one must understand the communication mechanisms used between the various organizations. This thesis concludes with implications for this research and future work ideas that can further the area of boundary object research.

1.1 Definitions

- Artifacts: Objects that individuals work with – the numbers, blueprints, faxes, documents, databases, parts, tools, and machines that individuals create, measure, or manipulate (Carlile and Schoonhoven 2002)
- Boundaries: Gaps or differences in organization structures or entities, political power, relative expertise, knowledge domains, etc. (Greer, Black et al. 2006)
- Boundary Objects: Objects that are flexible enough to adapt to local needs yet specific enough to maintain a common identity across different interpretations (Star and Griesemer 1989)
  - Objects that bridge gaps and enable collaboration across boundaries (i.e., a clay model of an engine)
- Community of Practice: A community with a shared understanding of what the community does, of how to do it, and of how it relates to other communities (Brown and Duguid 2001) (i.e., software engineers from the same company developing code)
- Disconnects: Latent differences in understanding among groups that can negatively affect the program should they remain undetected or unresolved (Greer, Black et al. 2006) (i.e., misinterpretation of a terms commonly used but with various definitions)
- Lead Systems Integrator (LSI): System of Systems manager (Laird 2003), who establishes and oversees an environment in which components of the system are

gradually but continually conceived, implemented, fielded, and evaluated (Bar-Yam and Kuras 2003) (i.e., Boeing)

- System of Systems (SoS): Complex systems that have components that are operationally and managerially independent (Maier 1998) (i.e., Future Combat System)

1.2 Methods

This thesis involved the collection of qualitative and quantitative data in a mixed mode research approach summarized in Figure 1. First, literature on boundary objects and system integrators were reviewed. This literature provided the basic fundamental principles of boundary objects and systems integrators. Next interorganizational interactions in US Future Combat System (FCS) were studied using publicly accessible information and eight supplementary interviews. The knowledge from the literature reviews and FCS case study was synthesized together to develop a boundary object model. This model was applied to TMOS. A series of statistical tests were then used to analyze TMOS survey responses. Lastly, the boundary object model was assessed through the case study concluding with implications for theory and practice.

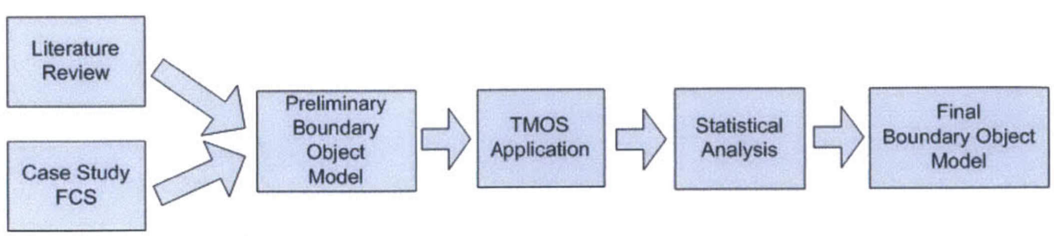

Figure 1: Summary of research methods

1.3 Chapter overview

The following section briefly describes each chapter in this thesis in sequential order.

Chapter 2: Evolving Role of the Lead System Integrator for System of Systems

This chapter presents background on System of Systems and Lead System Integrators concepts thereby providing a domain to which the rest of the research can be applied.

Chapter 3: Problem Statement

This section presents the two hypotheses for this thesis: organizational interactions can be improved and disconnects can be reduced by effectively using and representing knowledge via boundary objects, and the effective use of boundary objects can increase collective expertise and increase clarity of communication.

Chapter 4: Communication, Coordination, and Collaboration

The next section defines and explains the general principles of communication, coordination, and collaboration, and relates the effectiveness of these interactions with proper usage of boundary objects.

Chapter 5: Boundary Objects

This chapter defines and provides examples of boundary objects. A boundary object mental model and attributes model are also presented to assist in the understanding of boundary objects.

Chapter 6: Future Combat System Case Study

This section presents the approach and results from the US Army's Future Combat System case study. The Future Combat System is chosen as a case study because it is a clear example of a System of Systems with many different types of organizational interfaces and interactions.

Chapter 7: TMOS Case Study

This section provides background information on TMOS. In addition, this section presents and explains the approach taken in this case study.

Chapter 8: TMOS Results

This chapter conveys the TMOS case study results in the same topic order described in the approach section.

Chapter 9: Discussion

This section offers discussion on, amongst many things, the over reliance on people for information and the importance of traceability, inclusivity, and freshness in a boundary object. Implications and conclusions of this case study are also presented.

Chapter 10: Future Research and Conclusion

The last chapter concludes the thesis by extending this research to system integrator applications and suggesting possible topics for future research. Additionally, conclusions and a summary of this thesis are offered.

2 Evolving Role of the Lead System Integrator for System of Systems

A motivation for this research is to better understand the role of Lead System Integrators (LSI) in large System of Systems (SoS) through the application of organizational communication and boundary object knowledge. This chapter presents background on SoS and LSI concepts thereby providing a domain to which the rest of the research can be applied. The application of boundary objects to study system integrators will be revisited towards the end of this thesis.

2.1 System of Systems

Although there is a variety of definitions for a System of Systems (SoS) (Lane and Valerdi 2005), most of these definitions agree that a SoS has to have components that are operationally independent and managerially independent (Maier 1998). Operational independence of a SoS component means that it must be able to separately operate in a useful manner if detached from the SoS. The managerial independence of the SoS component means that the component is actually managed independently before and after it is acquired and integrated into the SoS (Maier 1998).

The benefit and need to form SoSs have been realized and studied in many different applications. NASA's space exploration initiative (Spurlock 2005), GEOSS (Lane and Valerdi 2005), a wide area network system, and an integrated air defense system (Maier 1998) can all be classified as SoSs. In a SoS, new capabilities of the whole system can be realized that were not possible with each of the individual components working alone. Furthermore, SoSs are needed as technical systems become more complicated. This is especially true for the US military as it tries to develop more complex and intricate military systems (Moon and Schoder 2005). However, developing new capabilities is no longer solely about the development of the most advanced technology (Nicoll 2003); the value and capabilities resulting from SoS integration needs to be realized. This value greatly lies in the interfaces of the SoS components. However, these interfaces are also where the most risks exist (Maier 1998). As a result, the ability and execution in which the systems integrator manages these interfaces are critical to the success or failure of the overall system.

This paper takes a unique approach in using boundary objects to understand the role of a LSI in a SoS. Boundary objects are important because they contain the information that is needed to communicate, coordinate, and collaborate between different stakeholder groups. The value of a boundary object depends on how successful it can decontextualize knowledge on one side of a boundary and recontextualize the same knowledge on the other side. As a result, the role of a LSI becomes tightly associated with how information and knowledge are translated using boundary objects throughout the system.

2.2 Lead System Integrators

US military systems are becoming more intricate and as a result the US government has been turning increasingly to and incentivizing industry contractors, relying on their knowledge to lead systems integration efforts (Moon and Schoder 2005). Furthermore, the government's demands upon the industrial world are changing. The emphasis is on having all systems networked in order to achieve maximum effectiveness so that all of the systems can create a common picture for all participants (Nicoll 2003). It is no longer solely about the development of the most advanced technology; there needs to be a transformation towards systems thinking in defense organizations (Nicoll 2003).

The traditional definition of a contractor is one that enters into a legal agreement to provide a product or perform a service in exchange for something else that is of value. Although there is generally a consensus that the LSI needs to oversee complex systems, its definition and obligations have not been formally defined. Table 1 provides some definitions and role descriptions for a LSI from the literature. A more comprehensive table can be found in Appendix A. There are some distinctions between these definitions, especially between the academic papers and articles released in industry. Industry released articles tend to focus on the contractual role of a LSI, while the academic papers emphasize the leadership and managerial abilities of a LSI.

Table 1: LSI deifinitions and roles

Definitions of LSI	Application	Context	
		Academic	**Industry**
-establishes and oversees an environment in which components are gradually but continually conceived, implemented, fielded, and evaluated (Bar-Yam and Kuras 2003)	Air and Space Operation Centers	X	
-[seeks] to leverage the work that is being done by others in a highly coordinated manner -act[s] as the vital link between sponsor on one side and these co-contractors on the other (Gupta 2003)	Air and Space Operation Centers	X	
-[are] specialized project managers (Nicoll 2003)	Department of Defense		X
-buy rather than build components and stitch together complex weapon systems (Crock 2005)	Department of Defense		X
-act[s] as an honest broker, even selecting competitor solutions over those from within its own company when cost performance or risk warrant it (Moon and Schoder 2005)	Department of Defense		X
-blend[s] existing and future capabilities into a highly effective system -[provides] a focal for implementing proven best practices across a program -standardize interfaces -[reduces] the role of the government in technical program management but retain the flexibility to allow the government to change the structure of a program team (Spurlock 2005)	Space Exploration	X	X

Despite these differences, there is consensus that a LSI will become the vital link between the customer and contractors. Communication within the enterprise is crucial for a LSI to create situational awareness for the customers and all other stakeholders. A LSI has to be able to interact in multiple communities of practices and organizational cultures to ensure that different groups are working together towards the same goal. As a result, a LSI must understand different stakeholder circles and how to create and maintain boundary objects that flow smoothly among all of the circles. This research will analyze organizational interactions through a boundary object model and apply the results to assess the roles and responsibilities of a LSI.

Two examples of a SoS that could benefit greatly from the guidance of LSIs are the future space exploration systems and Air and Space Operation Centers (AOC). In both examples, a LSI could reduce the overall development and operations cost of the enterprise through synergies, give each SoS focus, and improve mission success. Specific attributes of these systems are highlighted to emphasize these points.

Space exploration provides an example of how a LSI can blend existing and future capabilities into a highly effective system capable of supporting logistic systems by allocating existing resources, identifying gaps in capabilities, and filling those gaps (Spurlock 2005). There are many new programs associated with the future of space travel, such as the Mars exploration and the lunar exploration missions. In each of these exploration missions there are commonalities that are shared. An architecture for a space program that relies on a LSI to integrate across the system, find commonalities across the systems, and provide services as needed for each program will reduce each program's uniqueness, save cost, and reduce time normally needed for independent development and safety verification (Spurlock 2005). Furthermore, components and modules for one mission can be easily exchanged and used by other missions. Spurlock explains that a LSI can be used to free up NASA's resources by integrating cargo supply logistics across multiple space programs thereby providing similar service capabilities to different mission.

Moreover, the shifting challenges faced by the military have caused the US Department of Defense (DoD) to seek system-of-system management to deliver capabilities to the services and for joint military operations (Laird 2003). Within the last decade, small pockets of organized violence have become the norm in diverse geographies around the globe. The outbreaks have dramatically increased the number of American military deployment to small-scale conflicts where access by large heavy machines and vehicles is difficult (Mait and Grossman 2002). The relationship between government and industry is changing with the emergence of LSIs to deliver capabilities to the DoD for transformed operations. The key to this transformation is to fuse data and deliver common operational pictures to the forces, thereby enhancing the situational awareness of all those involved (Mait and Grossman 2002).

The AOC is a military example of a SoS that can benefit from the management of a LSI. At the highest level, the AOC is a weapons system used by the Air Force for planning, executing, and assessing theater-wide aerospace operations. An AOC consists of a large number of related, yet independent, systems which must all interoperate to affect the capabilities required to plan, conduct, and monitor the air and space war. During a full war environment, the AOC operates 24/7 with hundreds of professionals planning and executing thousands of missions every day (Norman and Kuras 2004). The objectives and missions of each AOC depend on its theater of operations. For example, the primary mission of the AOC in Qatar is the "preemption of terrorist acts," whereas the primary missions of the AOC in Korea are the enforcement of a treaty and the aid in the delivery of humanitarian relief (Bar-Yam and Kuras 2003). Identifying and capitalizing on similarities between different military systems are ways a LSI can help increase operational effectiveness. Realizing and designing system commonalities can also reduce wasted effort and resources to the overall system.

Even though LSI contracts are already being awarded by the US military, the value of a LSI is still not well understood. This may be due to the novelty of a LSI, its unclear function, contractual trust agreements, etc. A way to articulate value and also challenges associated with LSIs is needed. This research will study the usage of boundary objects at organizational interfaces and assess the extendibility of boundary objects as value indicators for LSIs. The next chapter presents the hypotheses for this research.

3 Problem Statement

Previous research has shown that technical and organizational interfaces in engineering projects and programs are highly coupled (Morelli, Eppinger et al. 1995; Sosa, Eppinger et al. 2003). Programs and projects suffering from organizational disconnects can lead to cost overrun, redesign, and rework. It is important for these organizational interfaces to be understood and managed by system integrators or other entities performing similar functions. Disconnects must be reduced while making communication interfaces more efficient. This leads to the hypotheses that:

1. Organizational interactions can be improved and disconnects can be reduced by effectively using and representing knowledge via boundary objects, and
2. The effective use of boundary objects can increase collective expertise and increase clarity of communication.

These two hypotheses were evaluated by studying how communication artifacts are used and treated at various interfaces within an engineering program. A boundary object model was developed to assess different artifact attributes that contribute to the artifacts' effectiveness as boundary objects.

This research also aims to assess if a boundary object attributes model can be useful in helping explain the roles and responsibilities of system integrators or Lead Systems

Integrators in a System of System. It is proposed that the roles and responsibilities of the LSI and other system integrators can be explained with a boundary object perspective by allowing for a clear understanding of how organizations and communities of practices interface and collaborate amongst each other. The validation of the hypotheses will not involve formal statistical tests given the impractical nature of doing a controlled experiment. However, descriptive statistics will be provided to show the usefulness of a boundary object framework in the context of a large complex military system. The thesis will conclude with a discussion on generalizations of these principles to other contexts and the limitations of doing so.

The next chapter will begin a discussion into the purpose and usefulness of boundary objects by focusing on their functionality at communication, coordination, and collaboration interfaces.

4 Communication, Coordination, and Collaboration

Before diving into boundary objects research, it is important to understand different types of organizational interfaces that can exist. These organizational interfaces are classified into three categories: communication, coordination, and collaboration. The following section defines these terms and provides a model to help understand their differences. The discussion in this section will provide a foundation onto which the boundary objects research can be mapped. Communication artifacts are considered highly effective boundary objects if they enable interaction at the collaboration level.

4.1 Communication

Communication is the process by which information is exchanged between individuals through a common system of symbols, signs, or behaviors (Merriam Webster Online 2007). Similarly, a communication event has been defined as a verbal or non-verbal exchange between two or more people (Lingard, Espin et al. 2004). In the context of SoS, an organization communication interface exists when two or more communities of practices transmit and receive information successfully and error-free. Communication can occur through a website used by a customer to post information about services it is seeking or it can occur through a prototype of a jet engine transferred between a supplier