**BAE Systems, Inc.**

**03/24/11**

**Concepts of Systems Engineering (SYS501)**

**CAPSTONE REPORT: Theatre Battle Management Core System (TBMCS) Systems Engineering Case Study**

**Carlos J. Lazo**

**AN INTRODUCTION TO THE TBMCS**

The Theater Battle Management Core System, also known as TBMCS, is an integrated air command and control (C2) system that provides the Combat Air Forces (CAF) and the Joint/Combined Forces with an automated and fully integrated capability to plan and effectively execute air battle planning for military operations and intelligence personnel worldwide. From a high level perspective, the TBMCS provides air commanders and battle strategists with means to plan, direct, and control/oversee all theater air operations, coordinating closely with ground and maritime operations engaged in similar excursions and operations. A detailed context diagram denoting some of the interface connections to and from the TBMCS can be seen in Figure 1:



Figure 1 - TBMCS Interface Linkage & Overview

The Department of Defense (DOD) continually requests the development of joint complex systems that will deliver needed capabilities and tools to our warfighters. In the case of the TBMCS, Lockheed Martin (LMCO) was chosen as the prime contractor, with the Air Force military branch established as the primary Government branch responsible for programmatic oversight. LMCO was given from 1995 – 2000 to release the 1st version of the TBMCS (V 1.0.1) for fielding. Even though the 1st release of the TBMCS brought with it many difficulties for LMCO and the Air Force, this complex case study showcases how one can use the Systems Engineering Lifecycle to transform a user’s mission statement and needs into a fully functional and operable complex system.

**STANDARD SYSTEMS PROCESSES IN TBMCS CASE STUDY**

The TBMCS required an enormous amount of effort at all points in the initial program life cycle, with successful completion driven by contributions from multiple agencies, contractors, and government affiliates. Given the complexity of the design and the end goal, the following list encompasses the wide variety of standard system processes described and seen in the case study:

* *Defining Needs, Operational Concepts, and Requirements*
  + The needs surrounding the TBMCS were defined by the Air Force and general Customer community. Operational Concepts and Requirements were defined as the program evolved, and were not established directly upfront due to lack of CONOPS.
* *Functional Analysis, Decomposition, and Allocation*
  + Once the interface connections to and from the TBMCS and the overarching system requirements were understood, LMCO began performing a functional analysis and decomposition of all interoperable components located within the system.
* *System Modeling, Systems Analysis, and Tradeoff Studies*
  + System models were created and analyses were done in an effort to emulate the operational environment of the TBMCS. Few tradeoff studies were performed.
* *Requirements Allocation, Traceability, and Control*
  + Proper requirements mapping and traceability was ensured throughout the development of the system, with the primary contractor and government as the main stakeholders in the process.
* *System Integration and Verification*
  + The system of systems was integrated as a whole, and through a variety of different test events and verification methods, was approved for theatre release.
* *Systems Engineering Product and Process Control*
  + Processes such as the Systems Engineering Lifecycle & QP Process Flow were used.
* *Configuration and Data Management*
  + As a DOD system, the TBMCS operated at multiple levels of government Classification. Configuration and Data Management was crucial to the project.
* *Risk Management Approaches*
  + A risk management process was put in place by the contractor, and involved Integrated Project Teams (IPTs), Working Groups (WGs), and constant risk assessment, re-assessment, and real-time implementation of lessons learned.
* *Operation, Sustainment, and Training*
  + Plans were put in place in order to understand overall system operation. With an aggressive schedule and new releases being fielded at least once per year, Life Cycle Support, Training Materials, and constant Help Desk support were essential in bringing life and success to the TBMCS.

**SYSTEMS ENGINEERING LIFECYCLE IN TBMCS CASE STUDY**

All primary areas of the Systems Engineering Lifecycle were touched upon throughout the five year duration of the TBMCS initial release. The case study itself identifies a total of nine different concept domain areas of the lifecycle (utilizing the Friedman-Sage framework matrix), with focus directed towards ***Phases A – E*** below (in bold italics):

1. ***Requirements Definition and Management***
2. ***Systems Architecting and Conceptual Design***
3. ***Detailed System and Subsystem Design and Implementation***
4. ***Systems and Interface Integration***
5. ***Validation and Verification***
6. System Deployment and Post Deployment
7. Life Cycle Support
8. Risk Management
9. System and Program Management

***The case study analyzed each of the five highlighted areas above in depth***, and associated a specific Learning Principle (LP) with each phase. This phase to LP mapping will be used to describe the subsequent parts of this report when discussing **strengths** and **weaknesses**. A summary of how each of these phases was handled is seen below, along with the respective **LP**:

1. ***Requirements Definition and Management***

**🡪 LP 1 –** The requirements process for producing the 1st release of the TBMCS was broken.

* Primary responsibility for this particular phase was on the Government. The Air Force did not initially develop a System Segment Specification (SSS), leaving the contractor to make assumptions and to derive requirements from legacy systems. In order to lessen risk and properly handle this phase, LMCO and the government formed a Systems Engineering IPT to manage all requirements for current and future releases.

1. ***Systems Architecting and Conceptual Design***

**🡪 LP 2 –** The system architecture was initially defined at too high a level, thus impacting the design and development of the system.

* Responsibility for this particular phase was shared between the contractor and Government. The Air Force mandated the use of 3rd party hardware and software products, which proved immature and insufficient from a reusability perspective. In order to lessen risk and properly handle this phase, a jointly developed “to be” systems architecture was created, with focus on modular open system standards.

1. ***Detailed System and Subsystem Design and Implementation***

**🡪 LP 3 –** The system and subsystem design was severely hampered by the complexity of legacy applications, misunderstanding of the maturity and complexity of commercial and third party software products, and the lack of understanding of how the system would be used and employed by the user.

* Responsibility for this particular phase was shared between the contractor and Government. Both the Air Force and LMCO underestimated the complexity that would arise in using inadequate 3rd party hardware and software application to develop the TBMCS. Legacy products and backward dependencies made system and subsystem design difficult. In order to lessen risk and properly handle this phase, a web-interface concept was developed, which allowed product flexibility, COTS upgrade capabilities, and easier user acceptance.

1. ***Systems and Interface Integration***

**🡪 LP 4 –** Integration for a system of this complexity was very difficult.

* Primary responsibility for this particular phase was on the contractor. LMCO greatly underestimated the complexity that would arise in using inadequate 3rd party hardware and software application to develop the TBMCS. Legacy products and backward dependencies made system and subsystem design difficult. In order to lessen risk and properly handle this phase, a web-interface concept was developed, which allowed product flexibility, COTS upgrade capabilities, and easier user acceptance.

1. ***Validation and Verification***

**🡪 LP 5 –** Testing on the TBMCS was problematic.

* Responsibility for this particular phase was shared between the contractor and Government. Mutually exclusive testing was initially performed at the start of the program, with little communication between the contractor and government agencies. In order to lessen risk and properly handle this phase, a joint test team was formed between the both parties, focusing on developing a solid integrated test plan.

**STRENGTHS, WEAKNESSES, AND AREAS OF IMPROVEMENT IN TBMCS CASE STUDY**

The ***5 phases*** of the TBMCS analyzed in this case study have defined **Strengths** (**S**), prevalent **Weaknesses (W)**, and opportunities for **Improvement (I)**. Examples from each of these areas with respect to the phases are listed below, with explanations regarding how and why they were categorized in their respective fields:

***Phase A*** – ***Requirements Definition and Management:***

**S1**: The requirements development process created between the contractor and the government reflected a strong effort to establish, and more importantly, maintain communication throughout the different phases of the systems engineering lifecycle. The figure below illustrates the Version Planning Process (VPP) both parties established for this phase of the program:



Figure 2 – Requirements Version Planning Process (VPP)

**S2**: Given that there were no formal requirements defined for the initial system Request for Proposal (RFP), LMCO sought the help of an external contractor, The MITRE Corporation, to assist in producing a Technical Requirements Document (TRD), which then formed the foundation for the contractual and mutually agreed upon requirements baseline.

**W1**: The TBMCS had neither a Concept of Operations (CONOPS) nor specific requirements that described how it would operate as a single, integrated entity. With no system specification to define the overall system, the lack of specificity led to the System Performance Parameters (SPPs) being defined as goals rather than defined, hard-set requirements. Without a solid requirements baseline off which to enter the subsequent phases of the program, testability holes were discovered in the latter parts of the TBMCS effort, where it becomes increasingly difficult to address issues.

**W2:** Hardware and software dependencies varied based on the service branch using the TBMCS. Many of the systems the these branches mandated for use were undergoing parallel development, and were not inherently compatible with one another, making the requirements development, design, and maintainability process difficult.

**I1:** Even though a CONOPS may not always be provided, it is imperative that the contractor be proactive in seeking clear direction regarding requirements development and prioritization. No assumptions should be made in an effort to accurately and rigorously define all SPPs.

**I2:** Use of legacy systems should promote upfront analysis regarding any potential hardware/software issues that may be encountered. The entire user community, contractor, and test agents much also agree to a set of formalized Measures of Effectiveness (MOEs). Prioritization, and perhaps even Internal Research and Development (IRAD) may be worthy investments.

***Phase B*** – ***Systems Architecting and Conceptual Design***:

**S1**: The operational data architecture was well defined and understood from the beginning. With modularity being at the forefront of this development effort, the architectural concept of developing a layered N-tiered Web-based interface lent itself well to establishing a plug-and-play environment.

**W1**: The contractor, LMCO, did not design the initial system in accordance with CS4IR or government mandated frameworks, nor did they use any tools (e.g. RELEX, System Architect, etc.) to create the architecture. Lack of initial focus led to a very high level and ambiguous design, with too much room for interpretation.

**I1:** The communications architecture for this phase of the system was not sufficiently designed, with a huge problem surfacing as a result of failing the 1st operational test. Developing models to help facilitate system and validate system architectures and design, along with trade studies, would help reduce this risk.

***Phase C*** – ***Detailed System and Subsystem Design and Implementation***:

**S1**: The TBMCS system design called for project migration and fully upgradeability over time (e.g. moving from a UNIX based interface to a PC client-based interface). Open software standards, such as the Java 2 Platform Enterprise Edition (J2EE) environment, were adopted for development. These paradigms allowed for design implementation flexibility and removed many inherent complexities. This facilitated the release of field capabilities at a much higher rate with less risk. The diagram below denotes the idea behind this migration, with a projection for work in the future:



Figure 3 – Web Migration and J2EE Upgradeability Plan

**W1**: The complexity of legacy system applications (which preceded the TBMCS) made new system design difficult. Integration between COTS and GFE products proved to be cumbersome, and not enough research was done to address these issues. Technology and data sharing interfaces that LMCO chose to use were still emerging and evolving in real-time, making it difficult to diagnose and understand intermittently recurring problems throughout all levels of test.

**I1:** Parallel development should be considered even throughout this design phase. Cognizance of future efforts, such as maintainability, sustainability, and upgradeability should be considered when choosing hardware/software platforms for development purposes.

***Phase D*** – ***Systems and Interface Integration***:

**S1**: LMCO excelled in their establishing methods in which to track their progress, planning against milestones using a Quality Point (QP) product review scheme. An integrated Product Timeline was also constructed, and masterfully mapped back to the QP product review scheme as seen below:



Figure 4 – Quality Plan (QP) and Product Timeline Integration

**W1**: The government customer forced constraints on the contractor regarding the use of COTS and GFE equipment. Approximately 90% of the TBMCS is comprised of these components, so integration of these subsystems with the overarching architecture required much oversight and additional overhead costs. Interfaces were not managed very well either.

**I1:** Given the specific constraints regarding the use of 3rd party or COTS product, the contractor should have the option to develop or suggest their own suggestion to the government should integration prove to be too difficult. The government must also be able to provide stable testing environments which the contractor can use to perform their integration.

***Phase E*** – ***Validation and Verification***:

**S1**: The contractor and the government formed a Combined Test Force (CTF), with representation from the different branches and services of both parties. The CTF was able to initiate and perform a mix of individual and shared tests. A short and efficient 6 month turnaround time is all that was required to move testing from the LMCO plant to a more realistically operational environment.

**S2**: Upon failing the 1st operational test of TBMCS, the System Program Director (SPD) resorted to risk reduction activities in an effort to ensure success for the next operational test event. Specific recommendations were made and lessons learned were employed to ensure success was more than probable and that risk was managed correctly.

**W1**: As stated in previous phases, a weak foundation in requirements definition made system validation and verification a painfully arduous process. Disagreements between both contractor and government test cases were frequent, and methods regarding the proper use of the system were varied and inconsistent. The knowledge base was strewn about multiple parties, with no clear centralized point of content.

**W2:** Testability throughout the preliminary design phases was severely hindered. Hardware limitations and inability to replicate realistic operational environments prior to the Formal Qualification Event (FQT) led to negative impacts on performance testing and masked issues regarding the system’s operational effectiveness.

**I1:** A good amount of thought needs to be placed on the Master Test Plan in the preliminary phases of the Systems Engineering Life Cycle. One way of ensuring both the contractor and the government are synchronized in thought is to hold a Test Planning Technical Interchange Meeting (TIM). The contractor presents their ideas regarding how their requirements will be mapped to test cases.

**CASE STUDY CONCLUSION**

The Theatre Battle Management Core System (TBMCS) Case Study was one that focused primarily on highlighting the pitfalls encountered in the systems engineering process of Lockheed Martin, the contractor which was awarded this prestigious but difficult contract. They learned many lessons in this time frame, and were able to take their weaknesses and turn them into strengths for future versions of this system. The systems engineering practices and principles, with particular highlight to Department of Defense (DOD) acquisition, are essential in driving this and any product involving a complex system of systems to a successful completion.