Requirements Development for the NASA Advanced Engineering Environment (AEE)

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ABSTRACT

The requirements development process for the Advanced Engineering Environment (AEE) is presented. This environment has been developed to allow NASA to perform independent analysis and design of space transportation architectures and technologies. Given the highly collaborative and distributed nature of AEE, a variety of organizations are involved in the development, operations and management of the system. Furthermore, there are additional organizations involved representing external customers and stakeholders. Thorough coordination and effective communication is essential to translate desired expectations of the system into requirements. Functional, verifiable requirements for this (and indeed any) system are necessary to fulfill several roles. Requirements serve as a contractual tool, configuration management tool, and as an engineering tool, sometimes simultaneously. The role of requirements as an engineering tool is particularly important because a stable set of requirements for a system provides a common framework of system scope and characterization among team members. Furthermore, the requirements provide the basis for checking completion of system elements and form the basis for system verification. Requirements are at the core of systems engineering. The AEE Project has undertaken a thorough process to translate the desires and expectations of external customers and stakeholders into functional system-level requirements that are captured with sufficient rigor to allow development planning, resource allocation and system-level design, development, implementation and verification. These requirements are maintained in an integrated, relational database that provides traceability to governing Program requirements and also to verification methods and subsystem-level requirements.

INTRODUCTION

Design and engineering analysis of complex and costly systems often requires analysis tools and expertise from around the country. Gathering all the necessary individuals and resources into a central location can be expensive, time consuming, and inconvenient for the individuals involved. One way to make the engineering process more streamlined is to develop the capability for engineers to share data and collaborate in a distributed environment. The Advanced Engineering Environment (AEE) is both a collaborative and distributed environment involving six NASA centers including Ames Research Center (ARC), Glenn Research Center (GRC), Johnson Space Center (JSC), Kennedy Space Center (KSC), Langley Research Center (LaRC), and Marshall Space Flight Center (MSFC). The AEE allows NASA to analyze space transportation architectures and technologies in support of the Next Generation Launch Technology (NGLT) Program and related activities.

The AEE is configured to facilitate data management, automated tool/process integration and execution, and data presentation. PTC's Windchill, Phoenix Integration's ModelCenter and an XML-based data capture and transfer protocol make up the AEE

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framework. The user interface, data management, tool execution and data presentation capabilities are directly and securely accessible from the World Wide Web.

The integration of tools within AEE uses Phoenix Integration's ModelCenter and Analysis Server software applications. Analysis Server essentially "serves up" discipline tool analysis capability. ModelCenter acts as the Graphical User Interface (GUI) that allows a particular user to control the tool(s) served by the Analysis Server(s). The Windchill Product Data Management (PDM) capability provides process/workflow management, web based access to project data stored within an Oracle database, and configuration management capabilities.

Reporting and visualization capabilities for various tools in the AEE environment are provided via a web interface. These range from detail to summary reporting and vary from tool to tool.

AEE Project formulation was initiated under the Intelligent Synthesis Environment (ISE) Program in 1999. Within the ISE Program, the project was organized as the Reusable Space Transportation System (RSTS) Large Scale Application (LSA). The ISE Program formed a partnership with the 2nd Generation RLV Program in 2000 – focused on acceleration of the RSTS activities. The ISE Program was terminated at the end of FY01 and thereafter the RSTS activities were retained and supported by the 2nd Generation RLV Program under the AEE Project. The AEE design was initiated in 2000, development activity was initiated in 2001, and utilization was initiated in 2002. The AEE Project was reassigned under the MSFC Systems Management Office (SMO) in early 2003 to provide support for the engineering/analysis requirements of multiple programs such as Next Generation Launch Technology (NGLT).

THE REQUIREMENTS DEVELOPMENT PROCESS

Given the highly collaborative nature of the AEE Project, many different organizations are involved in the development, operations and management of the system itself. Furthermore, there are yet more organizations involved that represent external customers and stakeholders. Thorough coordination and effective communication is essential to translate desired expectations of the system into requirements. Functional, verifiable requirements for this (and indeed any) system are necessary to fulfill several roles. Requirements serve as a contractual tool, configuration management tool, and as an engineering tool, sometimes simultaneously. The role of requirements as an engineering tool is particularly important because a stable set of requirements for a system provides a common framework of system scope and characterization among team members. Furthermore, the requirements provide the basis for checking completion of system elements and forms the basis for system verification. Requirements are at the core of systems engineering.

The AEE Project has undertaken a thorough process to translate the desires and expectations of external customers and stakeholders into functional system-level requirements that are captured with sufficient rigor to allow development planning, resource allocation and system-level design, development, implementation and verification. These requirements are maintained in an integrated requirements/decision database (IRDDB) using the CORE systems engineering tool that provides traceability back up to higher-level Program requirements and also down to verification methods and subsystem-level requirements. The IRDDB also provides a functional analysis capability and framework that enables the refinement of the requirements based on use-case oriented functional flows.

The overall requirements development process for AEE is based upon accepted standards and guidelines that have been appropriately tailored to this project. The standards and guidelines being used include:

- NASA Policy Guidance (NPG) 7120.5B, NASA Program and Project Management Processes and Requirements
- NPG 8715.3, NASA Safety Manual
- Institute of Electrical and Electronics Engineers (IEEE) 1220, IEEE Standard for Application and Management of the Systems Engineering Process
- MSFC-HDBK-3173, Project Management and System Engineering Handbook
- American National Standards Institute (ANSI)/EIA-632, EIA Standard, Processes for Engineering a System
- NASA-SP-6105, NASA Systems Engineering Handbook
- MIL-STD-961D, Department of Defense Standard Practice for Defense Specifications

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Furthermore, many of the systems engineers supporting these activities for the AEE Project are members of the International Council on Systems Engineering (INCOSE) and have attended various courses and seminars offered by INCOSE on requirements development and systems engineering.

Some details of the requirements development process for AEE are presented next.

IDENTIFYING CUSTOMER EXPECTATIONS

The term "customer" here is used synonymously with the term "stakeholder". In this context, the term customer or stakeholder refers to any person or organization that has a vested interest in the development and performance of the AEE system.

Customer (i.e., stakeholder, user) expectations for the products and deliverables associated with AEE are identified and flowed down from stakeholder requirements and plans. Face-to-face meetings and workshops are held with stakeholders, in lieu of formal documentation, to determine expectations for AEE. Explicit expectations that are represented as quantifiable requirements and performance parameters are captured in the AEE IRDDB so that traceability to derived AEE system requirements can be established and maintained.

DEFINING OPERATIONAL SCENARIOS

Operational scenarios that define the range of use of the AEE system are identified and developed based on discussions with developers and users. Upon identification, these scenarios are used primarily to identify system baseline functionality which will lays the foundation for functional analysis activities (e.g., functional modeling). Functional analysis then decomposes top-level AEE system functionality relative to its required behavior in performing analyses in support of stakeholder Program milestones and other identified operational/mission objectives. Scenarios were refined using Functional Flow Block Diagram (FFBD) techniques. Top-level scenarios, captured as discrete events (functions), will be further decomposed down to leaf-level system functions that reflect manageable threads of behavior (stimulus/response threads) are then be modeled and conveyed in detail using Enhanced FFBD (EFFBD) techniques. The NASA Systems Engineering Handbook, as well as most tutorials on disciplined Systems Engineering, provides further information regarding the application of functional analysis techniques to define required system functionality. Defining detailed AEE system functionality as a logical flowdown from the AEE mission life cycle ensures direct traceability between stakeholder operational needs and derived system functional requirements.

FUNCTIONAL ANALYSIS

AEE Systems Engineering performs functional analysis in coordination with the developers and users of the system. This is done in order to completely define the AEE system's functional architecture. This definition of the system's functional architecture is then used to structure and refine the system-level requirements. It should be noted that the functional requirements baseline will have been derived and flowed down from appropriate AEE operational scenarios, thus keeping stakeholder operational source requirements at the top of the functional hierarchy and maintaining traceability to these source requirements. Each function comprising the functional requirements baseline will be further decomposed to identify leaf-level system functionality if/as necessary. The functional requirements baseline and subsequently identified system-level requirements will be represented in FFBD notation as discrete events with associated quantifiable performance criteria. Early AEE Test and Verification involvement in this requirements analysis activity is necessary to ensure that AEE functional/performance requirements are verifiable.

Detailed functions identified as the result of functional analysis will then provide the basis for development of lower level Hardware and Computer Software Configuration Item (HWCI, CSCI) requirements. Again, traceability is maintained from the operational scenario level (FFBD), through the system functional requirements level (FFBD), and on to the allocated functional requirements level (EFFBD).

A Systems Engineering tool, CORE, is utilized to perform the functional analysis. This tool provides graphical functional modeling techniques (i.e., FFBD, EFFBD) and the capability to perform a complete functional analysis that produces an integrated and accurate functional hierarchy; it also maintains continuity from the AEE system root function and the functional context diagram through functional decomposition. The SE tool also provides for the identification of discrete performance parameters that will be linked to the associated functionality. Resulting AEE system and component functional requirements with associated performance

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then directly populate, via database query, the AEE System Requirements Document (SRD).

DEFINING SYSTEM BOUNDARIES AND INTERFACES

In general, any external influence to the functionality of the AEE system must be identified, captured, managed, and controlled ensure the correct format and integrity of all data received from, and transmitted to, external systems. The system of interest for this Project is the AEE system, including its required interfaces, software, and hardware components. The AEE system's primary data interfaces will be with the various sources of data for the architectures and technologies to be analyzed and assessed. Other systems external to the AEE that must be considered, particularly in support of detailed functional modeling, are those that provide direct and indirect stimulus/response functionality and observables (inputs and outputs). These external systems are currently minimally defined as the operator/user, sources of architecture and technology data to be analyzed, and external environment (i.e. other influencing events that impact system functionality). As the requirements analysis activity progresses, these external systems may be supplemented by additional identified systems with which the AEE must interoperate. It is also anticipated that the architecture and technology data sources will be further decomposed to identify each explicit source.

Functional and physical AEE system interfaces are defined in quantitative terms to ensure that they can be verified during system test activities. AEE Test and Verification participation in this phase of the AEE SE process is therefore necessary. Functional interfaces are established by considering the system of interest, the AEE, within its operational context, and external systems with which the AEE must functionally interoperate. Development and assessment of the AEE system's physical architecture will result in identification and definition of required AEE physical interfaces to which the functional interface requirements can be allocated. Subsequent functional analysis and synthesis activities will develop the detailed functional observables (inputs/outputs) that will be allocated to the applicable physical interface. The IRDDB is used to capture resulting system boundary and interface requirements.

DEFINING FUNCTIONAL REQUIREMENTS

AEE system-level functions are defined through decomposition of the AEE system's root functions. Decomposition of the AEE system's root function is based upon operational scenarios identified through discussions with developers and users. This approach ensures that required AEE system functionality is derived directly from operational needs, thus ensuring that system functionality meets stakeholder needs. It should be noted here that AEE System functional requirements will be derived from the stakeholder operational requirements rather than simply identifying analysis tools and/or their functionality, either currently in use or contemplated for future use. The identification of an analysis tool should represent a physical design/implementation solution that is captured at lower levels of requirements specifications (Level IV) and to which system-level functional requirements are allocated. The functional requirements resulting from this activity populate section 3.2.1, Performance Characteristics, of the AEE SRD. The IRDDB Function element class will be used to capture and decompose all derived system functional requirements. AEE system-level functions will be further decomposed and defined as a result of the functional analysis activities, including functional modeling.

DEFINING PERFORMANCE REQUIREMENTS

A complete functional requirement consists of two primary aspects: 1) The basic capability (function) that is required, and 2) the quantified performance criteria of the required capability. Multiple performance criteria may be associated with a single function or capability. Each performance criteria is maintained in the IRDDB, and linked to the corresponding function, using the Performance Index element class and the "exhibits/exhibited by" relation. Performance criteria will be defined for each AEE function and interface item to describe how well functional requirements must be performed. It is possible that system performance could be conveyed through non-functional requirements. It is also recognized that when a function, or other requirement is defined which has one aspect of performance, that performance criteria is more efficiently stated as part of the basic requirement rather than designating another IRDDB element to capture the performance criteria. Performance criteria will be determined in much the same way that corresponding functions are identified and defined as described in the preceding section. Detailed

functional modeling, primarily through the development of stimulus/response threads of behavior provide the primary framework within which to develop performance requirements. Other detailed performance criteria will flow down from stakeholder-stated needs and requirements regarding system performance metrics. These performance criteria will be derived from ongoing efforts by Systems Engineering to identify performance metrics that are critical to AEE stakeholders. AEE System performance criteria will be linked to the appropriate stakeholder source requirements. Early AEE Test and Verification involvement in this requirements analysis activity is necessary to ensure that AEE system performance requirements are verifiable.

DEFINING PHYSICAL CHARACTERISTICS AND OTHER QUALITY FACTORS

AEE physical characteristics (e.g., size, weight, finish) and other quality factors (e.g., reliability, maintainability) will be derived from stakeholder requirements and analysis plans. Since the AEE is a software support system rather than a flight system, it is anticipated that minimal physical and other quality factor requirements will be levied. Those physical requirements that are applicable will probably be associated with system availability and the user interface. Human factors requirements will therefore also drive AEE physical requirements. Early AEE Test and Verification involvement in this requirements analysis activity is necessary to ensure that AEE system physical and other quality factors requirements and environmental requirements are verifiable. The AEE SRD format, based on MIL-STD-961D and its associated Data Item Descriptions (DIDs), was used as a checklist to ensure that all potential physical and other quality factors have been considered for applicability to AEE and addressed as necessary.

DEFINING HUMAN FACTORS

To ensure that the requirements developed for the AEE system are user-centered and lead to a system that is usable, supplemental Human Factors and User Interface (UI) Usability evaluation activities will be performed by Systems Engineering. These activities are described in detail in the AEE UI Usability Evaluation Management Plan. The objective is to define the approach to supporting the development and implementation of the AEE User Interface Usability Evaluation Facility in the Army-NASA Virtual Innovations Laboratory (ANVIL). Results of

these efforts will be used to further support the definition of AEE non-functional requirements as well as functional and performance requirements.

THE SYSTEM REQUIREMENTS REVIEW (SRR)

Once the initial set of AEE system-level requirements was drafted based on this overall process, a System Requirements Review (SRR) was initiated to examine the requirements. The overall intent of an SRR is to confirm that the system-level requirements are sufficient to meet AEE Management's overall intent for the Project.

The specific objectives of the AEE SRR are to:

1. Confirm that the system-level requirements are sufficient to meet program/project/mission objectives. (Based on SRR guidance in the NASA Systems Engineering Handbook and MSFC-HDBK-3173)

2. Evaluate the system-level requirements to ensure they represent identified customer and stakeholder expectations and project, enterprise, and external constraints. (Based on SRR guidance in IEEE 1220 and ANSI/EIA-632)

3. Assess the system-level requirements to ensure that they are achievable within project resources. (Based on guidance in NPG 7120.5B)

4. Assess the system-level requirements for any conflicts and identify alternative functional and performance requirements where necessary. (Based on SRR guidance in IEEE 1220)

5. Conduct a preliminary Hazard Analysis. (Based on guidance in NPG 8715.3)

An SRR Kick-Off meeting was conducted to introduce the participants to the draft AEE SRD. This consisted of a summary-level review of the SRD contents, explanation of rationale for what is in the SRD and why, origination of the requirements, addressing questions, etc. Additionally, the Kick-Off meeting reviewed the guidelines for the generation of SRD Comment Forms and the disposition process. The Kick-Off Meeting marked the start of the SRR Review Period. The SRR Review Period consisted of the SRR Participants reviewing the AEE SRD in accordance with the objectives in this SRR Plan and generating SRD Comment Forms as appropriate. All

Comment Forms generated during the review period were forwarded to the AEE Project Management Team (PMT), who jointly screened the forms and determined the disposition (accept the comment for incorporation into the SRD, disapprove the comment, request clarification from the originator). This dispositioning process occurred over a series of teleconferences. This dispositioning process also generated a series of action items with the overall intent of refining the draft SRD. All SRD Comment Forms approved for incorporation, along with work completed and inputs obtained during the process of resolving the action items, was used to generate a final draft AEE SRD. This final draft was then used as the basis to establish the initial system-level requirements baseline for AEE.

The overall value of this process to the AEE Project was the generation of a stable, traceable and verifiable set of system-level requirements that helped establish an overall technical and management consensus on the design and development path of the system. This process also helped facilitate the discussion, negotiation and prioritization of new requirements.

OBSERVATIONS, LESSONS LEARNED AND CONCLUSIONS

The collaborative and distributed nature of AEE makes it a powerful system to conduct and support design and analysis activities. The very nature of this collaboration and distribution also means that there are a variety of organizations involved in the development, operations and management of the system. The fact that multiple organizations involved means that extra resources and effort are required to ensure effective coordination and communication to achieve consensus on the requirements. A high degree of collaboration is good but it usually means there are a larger number of external dependencies on the system that require management attention at multiple locations.

It takes alot of engineering analysis to perform the translation of customer and stakeholder desires into rigorously written functional requirements that are both verifiable and traceable. Systems engineering resources should be adequately scoped to ensure success on these activities, particularly for distributed and collaborative systems requiring more coordination with different organizations than similar development activities for systems that are less distributed and collaborative.

Security requirements can be difficult to define for collaborative systems due to differing computer security / firewall policies at various distributed facilities, etc. A balance needs to be struck between maximizing collaborative capabilities while implementing the right levels of security.

A common definition of terms among different organizations may sound like a small thing, but it is essential in order to achieve requirements, design and implementation consensus for a highly collaborative system.

Defining the boundaries of any system is a key to defining the requirements. A common understanding of boundaries, including physical, functional, and responsibility-oriented, is more difficult on a distributed and collaborative system where a variety of organizations are involved. Different organizations, whose local policies and procedures may not all be consistent, can view responsibilities and boundaries in different ways. Developing a common understanding across all the participating organizations is very important in refining and establishing consensus on the requirements. This is particularly true for Internet-based systems that house servers and other hardware (and software) components and networks, etc., in different facilities governed by different management organizations. A common understanding of the physical architecture and the associated external (and internal) boundaries has a direct impact on the ability to adequately define interface requirements, for example.

Alignment of requirements priorities is crucial for resource management, particularly where a variety of customer and stakeholder organizations are involved, who can have competing requirements priorities between themselves

Advanced electronic meeting / coordination methods are valuable but don't entirely take the place of face-to-face sessions at the working level. However, WebEx has turned out to be a very effective tool.