Requirements Engineering Efforts for LBNE and Evaluation of Requirements Management Tools

Anne Heavey, aheavey@fnal.gov

Erik Gottschalk, erik@fnal.gov

Fermilab, Batavia, IL

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Outline

- Intro to the Long-Baseline Neutrino Experiment (LBNE)
- What is Requirements Engineering and why do it?
- Getting started
- Input from Joint Dark Energy Mission (JDEM)
- LBNE's approach
- Evaluation of requirement-management applications
- Schema development
- Status
- Conclusions
- Acknowledgments
- Reference slides

The Long-Baseline Neutrino Experiment (LBNE) Motivation

- In May 2008, the Particle Physics Project Prioritization Panel (P5) declared:
  - "Measurements of the properties of neutrinos are fundamental to understanding physics beyond the Standard Model and have profound consequences for the evolution of the universe."
- … and recommended:
  - an R&D program in the immediate future to design a multi-megawatt proton source at Fermilab and a neutrino beamline to (the Homestake Mine in Lead, S.D., 1300 km away)
  - and carrying out R&D on the technologies for a large multi-purpose neutrino and proton-decay detector

- Background:
  - Neutrinos can oscillate (morph from one kind to another – e, τ, μ), implying they have mass; they had been thought massless.
  - The optimum baseline (distance between neutrino production and detection) for measuring oscillation parameters is 1000-2000 km.

LBNE Primary Science Goals

- Measure the parameters that characterize three-flavor neutrino oscillations

- Study a phenomenon known as CP-violation, which may help explain the matter-antimatter imbalance in the universe, and determine the relative neutrino masses

- If the detector in South Dakota is placed deep underground, it may also have the potential to:

  - Search for proton decay

  - Study neutrinos produced in Earth's atmosphere

  - Study solar neutrinos

  - Detect neutrinos from a supernova in our galaxy, predicted to occur about every 40 years

About the LBNE Project

- LBNE is a DOE Major System Project (TPC > $750M)

- Project Office at Fermilab

- Participation by other DOE labs and several U.S. and international universities

- Received DOE Critical Decision 0 (CD-0, mission need) approval in January 2010

- Aiming for CD-1 (alternative selection and cost range) approval in March of 2012

- Preparation for CD-1 has involved:
  - development of the WBS, conceptual design, cost and schedule,
  - continued R&D on the newer technologies and on scaling-up of proven technologies to the massive sizes required,
  - cost-reduction exercises in this era of severely limited budgets.

LBNE's Major Subprojects

- A new, intense neutrino beam driven by the Fermilab Main Injector in Illinois
- A near-detector complex on the Fermilab site to characterize the beam near its source
- A massive far detector 1,300 km away in the Homestake Mine in South Dakota
- Conventional facilities (caverns, buildings, infrastructure) at both sites

Each has its own requirements as well as dependencies on other subprojects.

Developing conceptual designs for two far-detector technologies:

- Water Cherenkov and Liquid Argon TPC
- Expect to settle on a single technology prior to CD-1

What's the problem?

- Reviews conducted last fall illustrated need for stronger requirements management:
  - design choices and parameters did not clearly flow back to the requirements
  - nor did either trace back clearly to the overall science objectives
- Many requirements documents existed
- Lacked centralized effort to standardize, unify or mandate traceability within and between them.

How to address it? Ask...

- What have others done?
- What are LBNE-specific considerations?
- What kinds of requirements does LBNE have and how do they flow?
- What types of related objects need to fit in the flow?
- What types of relationships exist between them?
- How big a job is this?
- What kind of tools do we need?
- Who's going to do the work?
- Begin informal research:
  - Google
  - Review LBNE and other projects' existing requirements
  - Read requirements management s/w documentation
  - Discuss with other requirements managers

Fermilab and DUSEL

- The Deep Underground Science and Engineering Lab (DUSEL, uncertain future) at the Homestake site has used IBM Rational DOORS
- At Fermilab, most projects have used standard documenting applications for requirements
- Fermilab is looking to assemble a suite of applications for its future projects to use, e.g.,
  - Primavera for project controls
  - SharePoint for collaborative workspace
  - Siemens' Teamcenter product "Engineering Process Management" for CAD
  - …
  - No product yet selected for requirements management
- DOORS application has been used by local JDEM collaborators
  - DOORS still licensed and supported at Fermilab

What is Requirements Engineering?

- A definition (not THE definition): The process of establishing the services (or functions) that the stakeholders require from a system and the constraints under which it operates and is developed.

- RE encompasses:
  - determining stakeholders
  - determining information needed by each stakeholder
  - determining management scheme and representational format of requirements
  - determining roles, responsibilities and schedule
  - eliciting requirements
  - documenting flow with appropriate hierarchy and interconnections
  - determining procedures for change control and maintenance

Goals for LBNE's solution

- Establish and implement LBNE-wide standards and procedures for documenting requirements and related objects (such as design parameters) such that they can be:
  - controlled, reviewed, traced, baselined and maintained throughout the lifecycle of the Project and Experiment
  - archived afterwards
- Select and adopt tool to facilitate these functions
- Use managed requirements documentation to simplify Conceptual Design Report and reduce inconsistencies in CD-1 document set
- Feed into the choice for a Fermilab-wide application

About the Joint Dark Energy Mission (JDEM)

- Discovery of Dark Energy in 1998
- NASA and DOE propose JDEM as one of three probes in NASA's "Beyond Einstein" (BE) program
- TPC > $750M (like LBNE)
- Three proposed concepts for JDEM:
  - SNAP, DESTINY and ADEPT
  - each uses a different combination of three science techniques
- Decade of R&D and project evolution
- JDEM is terminated in April 2011, after losing highest-priority space project status to Wide Field Infrared Survey Telescope (WFIRST)

(more complete timeline in supplementary slides)

Fermilab's Role in JDEM: Science Operations Center (SOC)

- Start developing requirements and cost estimates for the JDEM SOC in 2008
- JDEM SOC principal functions:
  - Interface with NASA Mission Operations Center to receive science and engineering data from the spacecraft.
  - Support instrument operations on the spacecraft.
  - Provide computing, networking and data-storage infrastructure for data-processing.
  - Establish a common software architecture and standards for data-processing and analysis software.
  - Provide secure, remote access to data.

JDEM Requirements for the SOC (initial round)

In July 2008 FNAL was given three months to produce requirements, an engineering design, and cost estimates (WBS) for a $30-40M Science Operations Center (SOC) with enough detail to survive a CD-2 Review.

- Three workshops were held to develop requirements and an engineering design for science operations
  - Requirements workshop at FNAL (July 23-25, 2008)
  - Requirements review at LBNL (August 21-22, 2008)
  - Engineering design workshop at LBNL (August 25-26, 2008)
- Requirements were based on science-operations use cases that were developed with scientist stakeholders during the first workshop
- A 40-page requirements document was completed for the SOC
  - The document included 18 subsections with a total of 105 requirements
- The requirements document was comprehensive, but difficult to review
  - High and low-level requirements were all included in a single document
  - No traceability!

JDEM SOC Requirements (2nd round)

- In 2009: charged to develop an R&D plan for the JDEM SOC and prepare for DOE and NASA reviews.
- Viewed as opportunity to improve software design and development process:
  - Selected DOORS software for requirements management
  - Used a DOORS requirements template developed for the James Webb Space Telescope (JWST) to define database attributes
  - Defined a process based on "Mastering the Requirements Process" written by Suzanne Robertson and James Robertson
  - Invited a consultant accredited with Project Management Institute
  - Selected IEEE templates for documents
  - Visited Los Alamos and Sandia to learn about agile computing techniques, applied in a DOE environment

JDEM's Approach

- Identify stakeholders early in Project lifecycle
- Identify roles of key stakeholders who will be users of the software
  - For the JDEM data-processing system, we identified 4 roles: algorithm developer, pipeline developer, data analyst, and operator
- Organize requirements to address the needs of these stakeholders
- Use requirements management software (DOORS) to define a **hierarchy of requirements**
  - Stakeholder requirements (highest level) are easy to review for non-experts
  - System requirements (lower level) define technical details
- Implement traceability to provide drill-down capabilities: explains how low-level choices satisfy high-level requirements
- Address validation and verification early on in the design process to show how the system will be tested at each level in the hierarchy.

Approach beginning to serve as a model for other projects at Fermilab

LBNE: Which tools to evaluate?

- IBM Rational DOORS
- Siemens also offers a Teamcenter product for "Systems Engineering and Requirements Management"
- Did not do wider search

Start with IBM Rational DOORS – it's installed and available!

Differences: LBNE and JDEM

LBNE's approach needs to suit both type and stage of project

- JDEM SOC effort was for software; we are a brick-and-mortar physics experiment

- LBNE is much bigger than the SOC portion of JDEM

- Our initial set of requirements exists, as does our WBS: we need to retrofit

- We have holes to fill (e.g., design choices based on experience rather than on a specific requirement)

LBNE's Approach

- Identify principal LBNE stakeholders
    - LBNE Project team (get experiment built on-time, on-budget)
    - LBNE Collaboration (ensure that experiment will satisfy science needs)
    - DOE Office of Science/HEP (review, approve and fund)
    - Fermilab (host institution; responsible for Beam, LAr and CF; also near site)
    - Other participating labs: BNL, LANL (responsible for WCD and ND, respectively)
    - Far site facilities institution
- Want a flexible management tool that will let us filter data as needed for each intended audience
    - don't want to define up-front the exact document output set
- Draft first in Excel, then import to management tool

LBNE Requirements for S/W Tool

Who are stakeholders and what do they need?

- Reviewers need to see flow-down:
  - Allow entry not only of requirements, but also of other objects in the flow-down chain, such as objectives and design parameters.
  - Create a link between two selected objects to document a relationship (e.g., parent-child or superseded-by-new).
- Project management needs flexible reporting:
  - Create a custom set of metadata fields common to all objects.
  - Filter on metadata fields to view, export and report on targeted data subsets.
  - Keep track of changes (who, what, when)
- Requirement authors need interface and access:
  - Import/export data from/to familiar formats (MS Word and Excel).
  - Be accessible for full access (read/write/execute) by at least three members of project team.
  - Provide at least read-only access to entire collaboration and project.

(LBNE's full list of requirements for tool is listed at end of talk, for reference.)

Tool Evaluation, Functional

- Evaluated functionality of both DOORS and Teamcenter (TC) requirements module
  - TC evaluated less thoroughly than DOORS
  - Held vendor presentations
- Both satisfy LBNE's functional requirements
- Some differences:
  - For versatile reporting with DOORS, also need RPE (Rational Publishing Engine) – more $$; built-in for Teamcenter (neither was tested)
  - TC more integrated with Microsoft products (e.g., edit requirement content in MS Word)

Evaluate Non-functional Issues (Implementation)

Issue	DOORS	Teamcenter
Cost	Computing Div already paying for a few sharable licenses, both rich client and web client	LBNE would bear total cost, at least initially
Implementation schedule	Available now at no initial cost to LBNE	Late fall 2011 at the earliest
Support and upgrades	Currently supported; long-term for LBNE: TBD	TBD
LBNE's vs. FNAL-wide goals	Local expertise available	Better fit with TC CAD

Evaluate Non-functional Issues (Accessibility)

Issue	DOORS	Teamcenter
S/W platform	Windows for rich client; browser for web client;	Windows and Web
Availability to distributed user base	Rich client requires VPN connection to Windows terminal server at Fermilab; Web client available; can share licenses or get cheaper Web-only ones.	Probably similar; licensing not fully investigated
Ease of use (scale of 10) *Anne's opinion; biased by more time spent with DOORS!*	8	6

Product Evaluation Conclusions

- (And the nominee is…) DOORS
  - Developed specifically for requirements management
  - Mature (~20 years)
  - Already supported locally with sharable licenses
  - Benefit from local expertise
  - Good fit with DUSEL at far site (relevant if DUSEL funding is restored)
- TeamCenter (TC)
  - Part of a suite of apps, one of which (CAD) will be installed at Fermilab (implies good interfacing capability)
  - Also meets our requirements, but…
  - I have not spoken with users of this TC module; no local expertise
  - Not available for implementation in June/July 2011 timeframe
- Disclaimer: I've done more work in DOORS, am more comfortable with it, and have tailored my schema to fit it (although it could be easily modified to fit TC).
- LBNE has not yet formally committed to DOORS, but appears likely to do so.

Schema development I

- Define hierarchy of objects to include in documentation:
  - Objectives → physics requirements → High-level beam and detector requirements → … → Low-level requirements → Specifications → Design choices
- Determine other objects that need to be included in the traceability structure
  - Objective, assumption, definition, narrative, objective, reference
- Define subtypes for objects
  - E.g., Requirement: Physics, functional, non-functional, ES&H, other regulatory, cost, schedule
- Determine metadata attributes for objects
  - E.g., status, parent, source, rationale
- Determine modularity – how best to subdivide and structure the info?

Schema development II

- Determine standards for writing requirements and specifications, e.g., each requirement *shall* be:
  - Necessary, verifiable and attainable.
  - Clear and unambiguous.
  - About one single issue (i.e., avoid "and").
  - …
- Define terminology:
  - Requirements use SHALL; they do NOT use: "is", "was" and "must."
  - Requirements NEVER contain: "but not limited to", "etc.", or "and/or."
  - …
- I assembled these standards based on various sources (see last slide).

Status of Effort

- Water Cherenkov far detector subproject started using Excel template in March. Feedback regarding the schema and instructions has helped it mature.

- Collaboration scientists are refining and documenting the high-level physics requirements according to schema.

- Engaging responsible parties in the subprojects (e.g., L3, L4 engineers)

- Holding tutorial sessions with the subprojects to train them on the schema and how to use the Excel spreadsheet.

- Determining schedule with respect to readiness reviews this fall

Next Steps

(Assuming LBNE adopts DOORS)

- Get formal DOORS training for 2-3 LBNE project members
- Complete/refine DOORS configuration
- Import data from the many Excel files
- Manually add links to implement traceability
- Train contributors on DOORS web interface
- Evaluate Rational Publishing Engine (RPE)
- If we purchase it, install and configure RPE
- Create targeted reports for internal reviews scheduled for next fall
- Complete CDR, with references to requirements documents.

Some observations

- The mere act of documenting requirements in such a structured way forces us to justify each choice we make (and thus each chunk of taxpayer money we spend).

- No matter what tool is used, it's a lot of work, but the right tools (used properly) can help identify and reduce errors, and make maintenance, change control and reporting easier.

- Need to make structure work for the entire project and collaboration → diverse needs and concerns

- Sociology is important in this type of effort
  - Buy-in from top management on all aspects is crucial
  - People (even scientists and engineers) can be resistant to change
  - Need to present clear motivation
  - Need to coach contributors on the thought process

Conclusions

- LBNE is committing itself to manage its scientific and technical choices, from top-level physics objectives and requirements down to the low-level individual component design parameters, in a structured, traceable system.

- We have developed a framework, captured it in a template, and people are starting to actively work in it

- I have recommended implementing DOORS

- Project management's decision not final

- Future Fermilab projects should benefit from the expertise gained and lessons learned by both JDEM and LBNE.

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- JDEM scientists and engineers: Erik Gottschalk, Vince Pavlicek, Jim Kowalkowski
- FNAL colleagues: Jerry Gugliemo, Dean Hoffer, Tony Metz
- DOORS users at Homestake: Steve Acheson, Charing Hage
- IBM DOORS rep: Ed Gafron
- Siemens TeamCenter rep: Ron Przybycien

Additional slides for reference

About the Joint Dark Energy Mission (JDEM)

- **1998:** Cosmic acceleration (Dark Energy, DE) discovered using Type Ia Supernovae

- **2000**: LBL proposes DE space telescope "SuperNova Acceleration Probe" (SNAP)

- **2003:** NASA and DOE create JDEM as one of three probes in NASA's "Beyond Einstein" (BE) program

  - Three proposed concepts for JDEM: SNAP, DESTINY and ADEPT; each uses a different combination of 3 science techniques (Baryon Acoustic Oscillations, Weak Lensing, Supernovae)

- **2007:** BEPAC assessment committee recommends that JDEM probe "go first"

- **2008:** NASA creates the Science Coordination Group to merge the three concepts into one, named "**JDEM-Omega**"

- **2009:** NASA creates Interim Science Working Group to develop lower-cost mission concepts

- **2010:** Astro2010 selects Wide Field Infrared Survey Telescope (WFIRST) as the highest-priority space project for this decade

  - WFIRST is based on the **JDEM-Omega** concept

- **2011:** DOE closes JDEM Project Office in April and discontinues WFIRST

- Full timeline in reference slide

Requirements for Req Mgmt tool (e.g., DOORS) I

The software tool used to document and manage requirements for LBNE shall allow the user to:

- Enter objects that can be treated as requirements.
- Enter objects that can be treated as types other than requirements, such as objectives or design parameters.
- Customize the list of object types.
- Assign a type to each object (e.g., requirement, design parameter).
- Create a custom set of metadata fields for objects (i.e., one set of metadata fields common to all objects). If the product auto-generates a set of fields, the custom fields would be additional.
- Enter and edit content of custom metadata fields for each object (any auto-generated fields may remain uneditable).
- Customize subsets of metadata fields to view, export and report on.
- View subsets of objects based on the content of a metadata field (e.g., view all objects of Type "requirement").
- Set and change the status of each object.
- Designate an object as obsolete (this may overlap with previous requirement).
- Create a link between two selected records to document a relationship (e.g., parent-child or superseded-by-new).
- Import data from familiar formats (MS Word and Excel 2007 or later suffice).
- Export data to familiar formats (MS Word and Excel 2007 or later suffice).
- Search on characters in any field for view-on-screen, export and report.
- Filter on multiple fields in order given (e.g., first by Type, then by Status)
- Restrict the values of any particular metadata field to a set list.
- Search using one possible value for fields having a restricted set of values.
- Sort objects by any field for view-on-screen, export and report.
- Sort on multiple fields in order given (e.g., first by Type, then by Status)

Requirements for Req Mgmt tool (e.g., DOORS) II

- Produce reports containing only a subset of objects, based on metadata field selection, and containing an arbitrary subset of metadata fields for the objects.
- Produce reports printable in 8 1/2 X 11 format.
- Produce reports in editable format.

The software tool used to document and manage requirements for LBNE shall:

- Track changes in all metadata fields for all objects.
- Add any new custom metadata field(s) automatically to pre-existing objects; leave field(s) empty of content.
- Maintain history of all changes: date/time, identity of person making the change, archive old data.
- Hold > 10,000 records, each of about 1kB.
- Support backup function without need for taking application out of service.
- Cost < $10k for a three-license equivalent.
- Be accessible for full access (read/write/execute) by at least three members of project team.
- Prevent conflicts/write-overs by simultaneous users.
- Provide read-only access to entire collaboration.

"Nice-to-haves"

- Provide configurable access rights either by user or user group.
- Illustrate impact of changed object on linked objects.
- Provide more complex search capabilities (e.g., 'green' in field A and NOT 'white' in field B).

References

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