Systems Subcommittee
SUBCOMMITTEE REPORT

SC3 Systems – 01 29 2020

Subcommittee Team Members:

Lydia Young - SLAC National Accelerator Laboratory
Ed Carroll - Sandia National Laboratories

Interviews and Documents Consulted / Referenced

- **(EC and LY) B. Ellis, T. Stevenson, J. Mitchell, P. Titus, S. Raftopoulos, A. Nagy, A. Jariwala, P. Dugan, Y. Zhai, T. Kozub, V. Riccardo**
- **(LY) L. Hill, S. Gerhardt, J. Galayda, H. Qualls, S. Languish, T. Jernigan, C. Ferguson**
- **Docs referenced include sampling from all those provided to K. Robinson.**
- **Tour of NSTX by S. Gerhardt**

Lines of Inquiry:

- Current engineering delivery for ongoing and future projects and initiatives (NSTX-U, FLARE, LTX, ITER, etc.)
- Virtual Engineering to design, model, analyze complex fusion machines
- Engineering capability needs for the next ten years
- Engineering Design Authority
- Systems Engineering (architecture, requirements, functionality, behavior, quality-V&V, and safety)
- The effective and efficient incorporation of quality assurance and safety into all endeavors
- The support of operations and maintenance of experimental programs and facilities
- Workforce management (acquisition, development, retention, succession planning)
- Effectiveness of the management and organization

SC3.1 Strengths/Best Practices

SC3.1.1 Findings:

- A number of interviewees expressed their confidence in the new engineering procedures and leadership .
- Engineering dept interviewees appear to understand their roles and responsibilities for COGs and Responsible Engineers, and are supportive of these roles.
- Several staff are training new engineers.
- Engineering staff members are appreciative of their access to the Engineering Dept Head (1:1's).
- Engineers with ITER experience expressed appreciation for that experience and also the recent PPPL engineering procedure changes.
- A Change Review Board is just starting to be stood up.
- There is one System Engineer, who has been on board for about a year, and has added a disciplined approach to organizing data (requirements, interface info, and so forth). His experience, knowledge, and willingness to work with others was acknowledged by the interviewees.
- There are 3 "go-to" technical experts. These people are respected for their deep systems technical knowledge.
- The Chief Engineer's role is clear to both the Chief and others, though he has been in the role for only a short time (October, 2019).

SC3.1.2 Comments:

- There appears to be universal understanding of the great importance to the lab that its user facilities have high availability.
- One small-project engineer stated he relies on the smallness of the team to conduct his work, and outcomes are good. For larger efforts, he worries that the processes are too high level and missing details.

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

- People seem comfortable with matrix assignments, when filling multiple roles across multiple projects (COG on one project, RE on another, project engineer on another, mentor on another).
- There is a concerted effort to model the entire NSTX (and agreement on the importance and value in having an integrated model)
- It is important that the organization determine ways to encourage/grow systems thinking amongst all of its staff and continue to integrate the systems engineering discipline in its processes and practices.
- What PPPL calls "Virtual Engineering" and related concerns refers to the level of fidelity needed for finite element analyses (FEA) used for design considerations / validations. The ability to perform FEA at the right level of fidelity for the current lifecycle stage of a project is something of an art form. There seems to be a bit of insufficient expectation from management, a need for a little more training, and perhaps a procedure update.
    - It should be a reasonable expectation that analyses conducted in the early stage of the project would be of low fidelity, and therefore take a short time to run. While analyses models created in the later stages of a project should rightly be high-fidelity models and consequently take longer to run.

SC3.2 Weaknesses and Risks

SC3.2.1 Findings:

- Windchill is a repository only for design documentation. There is insufficient staff and funding to oversee CAD admin duties, including Windchill.
- There is a new Doc Mgmt System that is not yet fully configured for use.
- The overall system architecture is contained only in the head of the engineering leader for that project.
- There were complaints about the complexity of analysis models (that these models were too high-fidelity).
- Insufficient IT support of digital Engineering Tools.
- Metrology expertise is not readily available.

SC3.2.2 Comments:

- The engineering department has only one Systems Engineer - showing a low-appreciation (or understanding) for the value that good Systems Engineering could provide to the department.
    - Industry research studies have shown a significant improvement in cost and schedule performance when Systems Engineering (considering all of the SE tasks - architecture, overall system understanding, requirements management, integration, validation and verification, configuration management, etc.) represents approximately 16% of the total program level of effort.
- Whereas systems engineering is a much-welcomed discipline to project and engineering organizations, it is important that staff not formally trained in systems engineering understand that systems practices are performed by many engineering functions, not only by the systems engineer. The following comments are indicative of things that could be improved by a proactive Systems engineering role.
    - In particular, one interviewee noted that ICDs belong to the Systems Engineer, though the engineer did contribute to ICD content and tracking. Typically, mechanical or electrical engineers have responsibility for generating their own ICDs, based on guidance by a systems engineer for completeness, change control, flow down, etc.
    - The analysis process appears to be inefficient (for example, knowing when to apply simple or complex models as a function of engineering development process).
    - The tools for passing info from requirements into analysis then analysis to design, and then back again should be optimized for ease of exchange of information
    - There appears to be mixed views of requirements traceability: some believe that the Systems Eng has done a good job setting a structure, others believe there is a gap between the physics requirements and engineering design.
    - The lack of a documented/visualized system architecture forces everyone else on the engineering team to try to guess where the boundaries are for their design work. The more complex the system, the more important explicit boundaries become.
    - Lack of low-fidelity analysis models: This reflects a lack of understanding in how to create low-fidelity analysis models. Low-fidelity models that are tightly integrated to mechanical or electrical CAD models enable conceptual design trade decisions, design exploration, and preliminary design validation. On the other hand, as a design moves closer to FDR, those models must be advanced into high-fidelity models that validate the design assumptions.

- The Design Review process was cited by several interviewees as being inefficient (too many or too much repetition or does not drill down on detail enough).
    - There may be a misunderstanding of the difference between a design review (peer-review) and a management review. Some engineering teams prohibit management from participating in peer-reviews. Peer-reviews should be technical, detailed, and actively seek design issues.
    - One interviewee expressed a literal definition of Peer Review (soft version of FDR, PDR, CDR), and did not seem to believe that Peer Reviews could be held to drill down on the design details the interviewee said were being overlooked. (It appears that Engineering Program Description (2.2.1.1.) and Eng 033 provide a reasonable general description of Peer Reviews.)
- One interviewee said there is confusion amongst OBS, SBS, and WBS , and when asked, could not say who is the master integrator of these 3 structures. Having a clearer explanation on how these complement one another might help staff better understand roles/responsibilities. This observation is reflective that the overall system architecture is only held in the head of the lead project engineer.
- When asked, one interviewee was unsure of who owns the "chit" list (and therefore, is driving completion of the line items within it).
- One interviewee indicated that the QA organization has added a redundant set of approval docs (QIPs) to travelers and procedures. The value added is not clear to the interviewee. Like systems engineering, it is important that staff include QA practices in their everyday work, and that QA staff provide needed guidance to engineers and technicians to ensure safe, effective, and high quality outputs in an efficient manner.
- Multiple interviewees express their worry about the sense of urgency by portions of the support staff (technicians).

- Lack of readily available metrology expertise during the design phase may impact installation efficiencies.
- There appears to be inefficiency in the flow of status information between procurement and engineering due to inadequate capabilities of the existing business tools at hand. Procurement has recently developed a Google-doc to dump status data for engineers to see. Currently, engineers seek out buyers to obtain status.

SC3.3 Opportunities for Improvement (Recommendations)

SC3.3.1 Imperative:

1. State the vision for an effective and efficient engineering development process flow (requirements -->architecture-->analysis -->design-->fab-->install) and with change loops within the project plan. Determine gaps and opportunities to improve effectiveness and efficiencies.
    a. The process flow need not be sequential, but parallel paths need to be pre-defined and managed carefully (not ad hoc).
2. Provide funding to improve doc/design management systems. Stand up the new Doc Mgmt System asap.
3. Draw on the knowledge/experience of existing staff members for ideas for optimizing engineering process flow and procedures. Select and incorporate improvements to help efficiencies.
    a. Provide an introductory course on Systems Engineering to all engineers
        i. Because PPPL currently only has one Systems Engineer, PPPL has an opportunity to define the role to the greatest level of benefit. We strongly recommend that PPPL consider elevating the role of the system engineer to the lead engineering person responsible for overall systems architecture. Then delegate Systems Engineering tasks in a coordinated way integrated with other engineering tasks.
    b. Provide in-depth training on Systems Engineering for select engineers (every project should have designated [and trained] systems engineers assigned)
4. In support of NSTX-R CD3B, review the Change Control process for materials, and determine gaps and opportunities to improve effectiveness and efficiencies.
5. In support of NSTX-R CD3B, review materials management processes, and determine gaps and opportunities to improve effectiveness and efficiencies of information/communication flow.

SC3.3.2 Long Term:

6. Determine roadmap and plan for updating and integrating business infrastructure (ERP, Doc Mgmt System, Design Mgmt System, manufacturing requirements planning-MRP- system, etc.)
7. Determine and implement a plan for providing project leadership training to promising scientists/engineers.

8. Determine and implement a plan to increase system thinking and decrease "silos" within/across departments and functions. Include approaches to integrate systems engineering and quality disciplines into everyday engineering work practices.

   SC3.3.2 Advisable:

9. Consider developing Windchill or other tools as well as use of the tools to enable MRP (Manufacturing Requirements Planning) digital output that can be readily shared with Procurement.
10. Use every opportunity possible to practice/train on processes that will lead toward management's vision of the culture they'd like. Apply processes, and pilot improvements.
11. FLARE: lack of as-built documentation may complicate installation and operation later on. The project team should consider the risks and formulate mitigation plans.
12. Determine building blocks for Virtual Engineering - Finite Element Analysis (FEA) - to influence designs, design trade studies, and design exploration. Some guidelines are provided with this report as reference material, but this topic is probably better resolved by bringing in a training program focused at this topic (also called, reduced order magnitude analysis models). It is difficult to present a rigorous mathematical formulation for justification that points to exactly what level of fidelity is required for any application or stage of the lifecycle of a system. If there are no procedures written that address methods for determining the correct level of fidelity for each stage of the project lifecycle, then it is recommended that guidelines be written (perhaps with the help of a training or consulting partner). Some examples of where low-fidelity models are appropriate include:
    a. Exploration of new systems or CONOPS
    b. Design trade studies for accelerated design iteration
    c. Requirements verification
    d. Digital qualification (simulation modeling)

SC3.4 General Comments:

- Overall it appears that many of the interviewees appreciate the increased Engineering process rigor that has been introduced in the last couple years. However, several expressed frustration that the rigor may be too much in some areas. The projects and line management should work together to identify where the biggest inefficiencies lie, and then determine together how to improve without compromising the end goal of facilities that can be safely installed and operated. Process tailoring is an important part of managing a portfolio of engineering projects. Processes appropriate for the NSTX project will significantly overwhelm small projects and processes appropriate for small projects will hardly ensure success for the NSTX project. As noted in some of the Comments above, it is critical that the design/installation staff understand that systems and quality are as much their responsibility as those who have expertise in these disciplines. The lab has a number of staff who are systems thinkers - we recommend a goal be set to make "systems thinking" part of the culture - this may help reduce the current view of engineering as a mere service group. Further, encouragement of technical staff to broaden their systems knowledge has additional benefits: worker morale, reduce "silo", increase organizational nimbleness, etc. The current business infrastructure is barely good enough to support the relatively low number and size of projects PPPL now has, and without reasonable attention and investment, the infrastructure will be woefully inadequate to support any large future projects.

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY NNSA