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ENGINEERING SUPPORT ACTIVITIES AT ELI-ALPS THROUGH A SYSTEMS ENGINEERING PERSPECTIVE*

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Abstract

ELI-ALPS will be the first large-scale attosecond facility accessible to the international scientific community and its user groups. The core business of ELI-ALPS is to generate attosecond pulses and provide these to the prospective users. In order to reach this ultimate goal, one key support area, the engineering development of complex systems as well as the engineering custom design service, has been systematically elaborated based on the standards, recent results, trends and best practices of systems engineering. It covers the boundaries towards all related support areas, from building operation and maintenance, to the custom manufacturing provided by the workshops, with the intention to make the model as well as the daily work as comprehensive and consistent as possible. Different tools have been evaluated and applied through the years, however, a key lessons learned is that some of the most important tools are teamwork, personal communication and constructive conflicts.

INTRODUCTION

Extreme Light Infrastructure (ELI) is the first civilian large-scale high-power laser research facility to be realized with trans-European cooperation in three sites. ELI's long-term objective is to become the world's leading user facility utilizing the power of state of the art lasers for the advancement of science and applications in many areas of societal relevance [1]. The main objective of the ELI Attosecond Light Pulse Source (ELI-ALPS) pillar is the establishment of a unique attosecond facility that provides ultrashort light pulses with high repetition rates.

The typical layout of *beamline systems* at the ELI-ALPS is as follows (see Fig. 1): the laser source produces pulses in the femtosecond duration range, which is connected via a beam transport system to one or more secondary source(s). Secondary sources are designed to produce attosecond pulses from the femtosecond laser pulses by utilizing various technologies based on Gas High-Harmonic Generation (GHHG) and Solid High-Harmonic Generation (SHHG). Beamline systems may have end stations as their closing system.

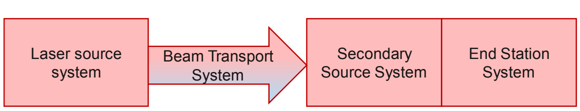

Figure 1: General model of a beamline system-of-systems from a laser until an end-station.

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Engineering services are really at the heart of the ELI-ALPS research facility: it is heavily connected towards the research technology as the major internal customer; however, it also has strong connections towards all other areas. In order to satisfy all expectations originating from this key role, the elaboration and organization of engineering support activities heavily considered the best practices and standards of systems engineering.

The next section summarizes the relevant best practices, standards and key works related to the scope of the paper, this way giving a sound foundation for the latter sections. Afterwards, first a big high-level picture elaborates the background and context of engineering services and then the organization of these engineering services is described.

RELATED WORK

Reference [2] lists the relevant (>30) systems engineering standards. Each focuses on specific aspects of systems engineering, especially on processes and lifecycles, as well as on vocabulary and risk management. The guide also gives a comparison as well as guidelines how to choose and how to apply these standards. A popular standard is ISO/IEC/IEE 15288 [3]0.

The openSE systems engineering framework has been developed as a common effort of research infrastructures, academic institutions and industrial partners [4]. It investigates and discusses the specificities of scientific projects regarding systems engineering and project management, with a dedicated focus on radiation safety. The framework provides an adapted and optimized systems engineering approach (in terms of lifecycle, roles and responsibilities, processes and deliverables). The framework emphasizes that scientific projects are their own prototypes, a one-of-a-kind system with an extremely complex nature and, because these reasons, the functional requirements are evolving whilst the project progresses. The authors also described that the final users, the scientific scholars taking an active part in the development effort and most of the time, they also lead projects, as it is the case also for ELI-ALPS regarding all the research technology equipment.

System integration is defined as the composition of implemented system elements into a product or a service for final validation, use and/or production (meanwhile checking the interfaces of the integrated elements) [2]. However, the systems engineering literature also refers system integration several times in a broader context, i.e. the simultaneous design and development of the systems and elements, virtually integrating designs in the early phases. System integration occurs on different levels: within a discipline, in multiple disciplines and on a socio-technical level [2]. Reference [5] introduces the W-model with the concept of continuous, virtual, cross-discipline integration and verification as early as possible.

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PMI [6] and INCOSE [7] formed a strategic alliance with the support of the MIT CEPE consortium [8] in order to advance the integration of the systems engineer and project manager roles. One of their book is about the best practices of systems engineering and project management through the application of lean principles [9]0. For example, the 3.2.3 best practice is the importance of not outsourcing or subcontracting the systems engineering activity, meanwhile the 5.1.3 best practice is about training the team to recognize and understand the internal customer – internal supplier value stream.

The authors of a related article about surveying individual and organizational acceptance of systems engineering methods [10] found that even the term "systems engineering" can be understood in different ways. Furthermore, the application of new systems engineering methodologies are hindered because different reasons (circumstances of the company, disadvantages of the new methods, too many options, etc.). The authors list recommendations for systems engineering methodology developers based on their findings. A common opinion of all interviewees was that the communication is more important than any tool. However, traditional meeting practices are not appropriate for efficient interdisciplinary communication but systems engineering methods are required. Similar findings appear in several other works as well [9, 11, 12].

PMI published a report about the essential role of requirement management and analysis [13]. The most risky requirements are those, which are self-evident and implicitly assumed by the end user [11, 14]. The Kano model describes that the customers and users rarely mention explicitly these important, "must-be" requirements, instead they consider these as evident and expected ones [15].

Briefly summarizing, all of the most relevant works on systems engineering agrees that communication and common understanding has a crucial role. Therefore, the elaboration and organization of all engineering support activities, services and workflows at ELI-ALPS has been driven to address this key aspect.

BIG PICTURE

As already mentioned, one best practice is training the team to recognize and understand the internal customer – internal supplier value stream [9]. Therefore, in order to have the common understanding about the role and place of engineering support services, two models were developed during the recent years with common notations (see Fig. 2): one is about the major areas, while the other is about the high-level workflows.

Major Areas

In this model (see Fig. 3), three major functional areas have been identified:

- Research Technology Services that includes the three types of research equipment: laser- and secondary sources as well as end stations, which together form the user platform. This platform is the foundation for the user service, which includes all the technical preparation and support for the user.
- Engineering Support Services that has two parts: the Hosting Environment and the Engineering Services for laboratories. The former is about the building (e.g. temperature and humidity stability of labs, cooling water, electricity) and IT services (e.g. data network, HPC), meanwhile the latter is about the direct engineering support (e.g. control system developments) for all research equipment.
- Business and Administration Services supports the previous two in everyday business and administrative manners (e.g. supply chain including procurement, contracting; user office, etc.).

Figure 2: Color-coding and notations.

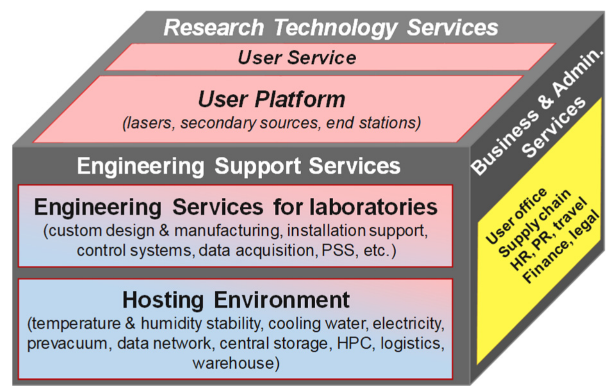

Figure 3: Major areas.

High Level Workflow

The combination of the previously introduced major areas model together with a value-chain [16] resource-chain model as well as with operations management principles [17] makes it more clear the role and place of engineering services. This model (see Fig. 4) focuses on and detail the relations toward the Business and Administration major area meanwhile the relations toward the Research Technology Services are discussed in the later sections.

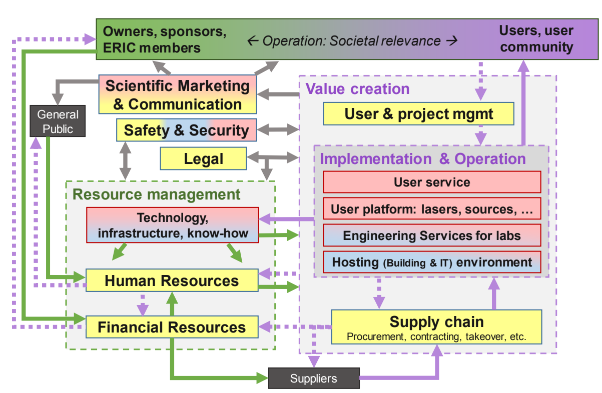

Figure 4: High-level workflow.

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ENGINEERING SUPPORT SERVICES

In order to increase common understanding among team members several life cycle, workflow and system models and views were developed during the recent years. The following subsections briefly introduce the latest versions of these, certainly to be further developed and adapted in the future.

Engineering Lifecycle

The engineering lifecycle (see Fig. 5) encloses the traditional engineering disciplines (software engineering, electrical engineering & workshop, mechanical engineering & workshop) as well as the vacuum technology (and all equipment, typically vacuum-related, assembly). Besides these, it applies a general engineering workflow: concepts, then the design, production & implementation, installations & test and finally the handover phases. All these traditional engineering disciplines and general phases are encompassed by systems engineering activities as an integrative channel to all surrounding stakeholders and systems. These systems engineering activities cannot be mapped only to one unit in spite of the fact that there is a dedicated unit covering this activity: in practice, every area should work on systems engineering together, besides the above mentioned engineering fields also the building services engineers, the scientists as well as the IT colleagues are frequently involved.

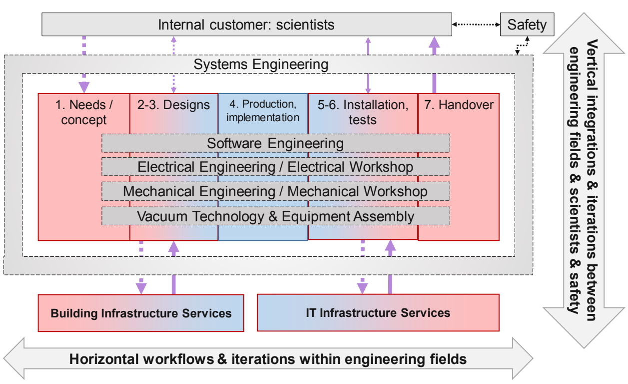

Figure 5: Engineering lifecycle.

Engineering Workflow

The engineering workflow (see Fig. 6) follows the formerly described engineering lifecycle in several aspects as well as it extends the basic principles laid down there. The general systems engineering activities are managed by a dedicated group, however, in case of engineering service systems (e.g. Personnel Safety System, Vacuum Control System, etc.) or in case of simple and local works related only to one specific group, the respective group coordinates and integrates all the works.

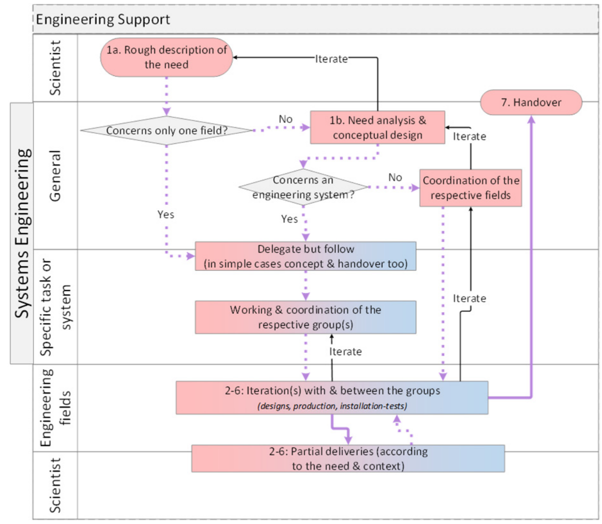

Figure 6: Engineering Workflow.

Systems and Layers

The lifecycle and workflow models focus on how to organize the work but not on the work itself. However, it is also important to have a common understanding and foundation about the basic architecture of systems and crosscutting general layers (see Fig. 7). The key points are the followings:

- as the major area model already defined, the key research technology equipment are the laser source (mostly black-box turn-key), secondary source (mostly grey-box common development with external experts) and end station (mostly black-box turn-key) systems. However, as the laser sources are hosted in separate and dedicated labs, in order to make the daily operation more efficient and safe as well as because of the different clean room conditions, beam transport systems are also required to interconnect the lasers with secondary sources
- besides these key research technology equipment it is also important to acknowledge and keep in mind the laboratories hosting these systems, as well as the hosting systems around (e.g. a vibration monitoring system installed throughout the facility in all labs)
- these systems usually encompass the following internal layers: the research technology layer (including optics, diagnostics and basic technological processes) is the starting point of everything and any further works, imposing requirements for all further layers; then the vacuum-, mechanical-, electrical- and software-layers are coming in this order basing on each other.

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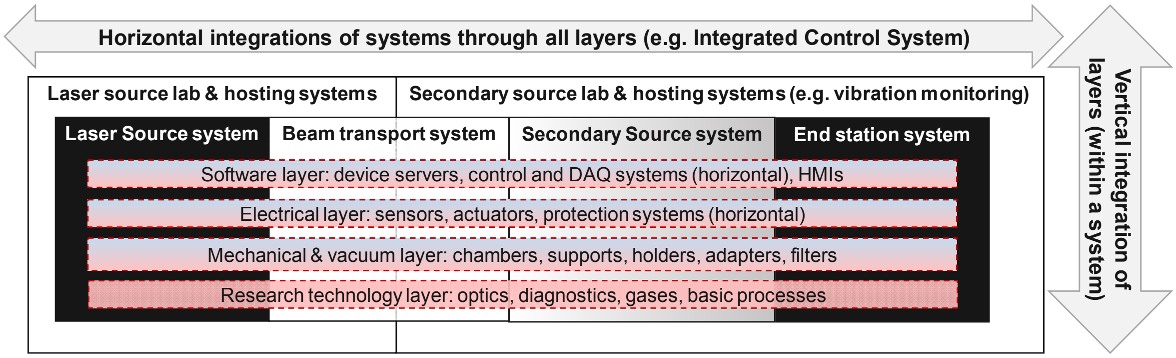

Figure 7: Systems and layers.

Control Systems

Control system development has three major directions: vacuum and gas control system (VGCS), optical control system (OCS), and the central integrated control, monitoring and data acquisition systems (ICS). The VGCS and OCS have to be built mainly from individual hardware devices procured by ELI-ALPS, while the ICS has to deal with every subsystem in its environment (see Fig. 8).

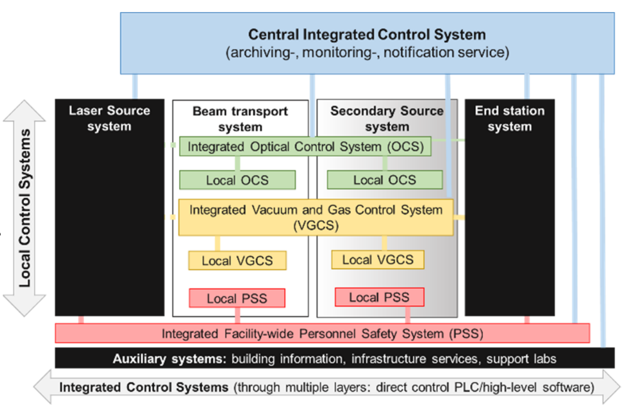

Figure 8: Control Systems.

Risk Assessment Methodology & Tool

The final model (see Fig. 9) is about to help the identification of potential systems engineering issues. It is the adaptation of a similar model introduced by the authors in their former paper [18]. Briefly summarizing its key points:

- a gap, i.e. missing functionality could happen between two systems and/or layers, which is certainly caused by a similar gap between two workflow steps and/or even between major / minor areas
- an inconsistency, i.e. interface mismatch could happen between two systems and/or layers, which is certainly caused by a similar inconsistency between two workflow steps and/or even between major / minor areas
- a redundancy, which is a special case of inconsistency

These potential systems engineering risks are managed and addressed by several means: traditional gate documents like Conceptual Design Reports, Technical Design Reports, detailed reviews in several iterations, as well as with checklists (e.g. the so-called requirement sheet aiming to survey what is required by the user, what is provided by ELI-ALPS and what the user brings with herself).

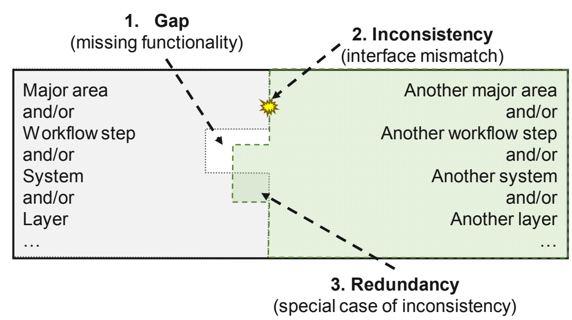

Figure 9: Systems engineering risks.

SUMMARY

In this paper, the systems engineering strategy and methodology underlying the engineering support services of ELI-ALPS has been introduced. Briefly, many relevant works on systems engineering agrees that communication and common understanding has a crucial role. Therefore, the elaboration and organization of all engineering support activities, services and workflows at ELI-ALPS has been driven to address this key aspect. These systems engineering models and activities has supported the development of the PSS system [19] as well as the control systems [20] too.

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