Systems Engineering for Computing Systems at Accelerator based Research Facilities

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Abstract

Large research facilities are major research enablers for expanding fields in various natural sciences. Traditionally built for physics and astronomy, nowadays fields like life sciences, medicine, molecular sciences and material sciences have become the driving forces, especially for particle accelerator based research facilities. Driven by the ever-increasing expectations of the scientific user community, new research facilities usually introduce novel technical concepts and architectures customised for the addressed research communities. Thus they represent the state-of-the-art in the domain, usually in a unique configuration. Continuous upgrades and adjustments to research trends entail that research facilities maintain a prototypical character throughout their lifetime, leading to a significant degree of openness as a system.

This persistent trend among research facilities has resulted in high degrees of technical and operational complexity. Today’s research facilities are complex socio-technical systems posing challenges to their development, construction, operation and maintenance. The need for multi-disciplinary engineering and the coordination between the diverse internal and external stakeholders make the application of Systems Engineering (SE) highly desirable. Therefore, this thesis assesses the socio-technical factors and proposes methods for applying SE in the particle accelerator domain for effective operational management.

A common theme in the technical design of large research facilities is the heavy reliance on control and computing systems in virtually all operational and maintenance processes. The application areas of control and computing systems include system control and monitoring tasks, data acquisition and processing, the provision of networks and a variety of software-based services. Both in-house users and temporarily visiting research groups depend on these control and computing systems. The controls and computing systems domain is especially affected by the mentioned engineering challenges due to its broad range of application cases and its highly integrative role in the research facilities; the facilities are thus complex socio-technical cyber-physical systems.

The thesis addresses the application of Systems Engineering and Systems Thinking at large research facilities, in particular for the development of control and computing systems. The research has been performed as Action Research activities at the European Spallation Source, a world leading spallation neutron source currently in construction and at the synchrotron light source MAX IV, both located in Lund, Sweden. The research contributions of this thesis are in the areas of System Integration, Requirements Engineering, Communication pragmatics in engineering, Systems of Systems Engineering, reliability and Systems Engineering Management. More specifically, the following contributions are presented:
An Integration Strategy that establishes SE for control systems at the ESS has been elaborated. It is based on the informational needs for successful integration. The approach guides the generation of integration-relevant information, and supports its accessibility and management by utilising System Integration Management Plans.

A novel approach to the process implementation for Requirements Engineering (RE) has been developed. It is based on tailoring views, activity patterns, informational structures, tools and services, and has been applied to the ESS control system development. Benefits of treating the RE process implementation itself as an Agile project are presented.

Systems of Systems (SoS) Engineering has been tailored for application at the ESS regarding mission critical systems. This case study investigates the SoS concepts for research facilities and indicates their suitability. Further, the Systems of Systems Engineering tailoring has been inspired by and drawing upon key concepts from functional safety standards in order to meet the high reliability expectations towards the ESS. This approach presents a way to achieve high reliability goals for complex systems that surpass more traditional system complexity levels.

A support concept for Systems Engineering Management (SEM) in environments with low degrees of stable, consistent development processes and documentation quality is also presented. The concept, named Conceptual Reasoning, describes the utilisation of viewpoints and the interrelation of elements between them on a conceptual level. Conscious improvement of Conceptual Reasoning practices in system developments is a way to enhance the success of crucial stakeholder communication.

All solutions were derived from and tested in the Action Research setting. The practical utilization of Systems Engineering in multiple, domain-typical system developments has been continuously analysed for barriers to SE application, and resulted in recommendations for Systems Engineering Management (SEM) in the domain. An SEM reference model is presented as a support tool for Systems Engineering managers in the domain, which aids in the identification of SE problems.

Future research goals are motivated and research methodology aspects in this field are discussed in order to encourage further progress.

Keywords
Systems Engineering, control system, computing system, particle accelerator, research facility