openSE

an **open**, **lean** and **participative**
approach to **systems engineering**

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openSE
is an outcome
of the PURESAFE Initial Training
Network FP7 Marie Curie Actions
project that is supported by
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Contents

Preface

The openSE framework is an outcome of the PURESAFE [1] Initial Training Network Marie Curie Actions project.

More specifically, openSE is the main deliverable of work package no. 1 entitled “Process and Modelling”, that aims at enhancing project management and systems engineering practices for projects related to the development of scientific facilities emitting ionizing radiations or of systems intended to operate in environments with artificial ionizing radiation. This framework pays particular attention is to safety and *remote engineering* aspects throughout the whole lifecycle of these facilities or systems.

The openSE framework is also a deliverable of work packages nos. 2 and 3 entitled “Remote Handling Hardware Platforms” and “Remote Handling Software Platforms” respectively by means of guidelines that are associated to the present document. To some extent, openSE is also a deliverable of work package no. 5 related to the dissemination of the PURESAFE ITN outcomes.

What is openSE ?

openSE is a systems engineering framework, i.e. a project management framework suited to projects that consist of developing complex technical systems. More specifically, it is intended to provide means to efficiently manage development projects of complex systems subject to or emitting ionizing radiation, while paying particular attention to four important aspects that may otherwise be omitted because of the natural focus that is naturally given by the project team to the project deliverable itself. These five aspects are known under the ORAMS acronyms that stand for Operability, Reliability, Availability, Maintainability and Safety. Several studies have shown that out of the many challenges a complex system development pro-

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[1] PURESAFE stands for “Preventing hUman intervention for incREased SAfety in inFrastructures Emitting ionizing radiation”.

ject team has to face, having to produce the fully functional final deliverable concentrates most of the project team's efforts to the detriment of several ORAMS aspects. Because the success of a complex system development project relies on the capability of the project team to address appropriately all ORAMS aspects, openSE provides means to deal with these five points of focus in an integrated way.

Why openSE ?

The development of this dedicated framework is motivated by the observation that project management and systems engineering standards and methodologies, be they of general purpose such as PMI's *Project Management Body of Knowledge* [31] or more specialized such as NASA's *Systems Engineering Handbook* [24], are not fully suited to development projects of scientific facilities emitting ionizing radiations or systems subject to ionizing radiations. It should be noted that scientific facilities or systems are importantly one-of-a-kind systems of an extreme complex nature. Project management and systems engineering frameworks designed for space development projects are partially suited to them, but they do not adequately take into account safety and remote engineering concerns to the level of requirements for scientific facilities emitting ionizing radiations or systems operating in environments with artificial ionizing radiations.

The openSE Governing Principles

Five principles governed the development of openSE , namely: openness, leanness, participation, modularity and scalability.

Openness. The aim of research projects consists of creating knowledge and, in fundamental research at least, of disseminating and sharing it widely in a non-commercial framework. For this very purpose, the scientific community is also more inclined to use *open products* (open source software, open knowledge, open innovation, etc.) that result from selfless initiatives when such products exist and have similar levels of efficiency with commercial products.

Leanness. Because project and systems engineers and designers who are the primary group of beneficiaries of openSE are not management professionals but engineering experts, they are not necessarily keen to spend time on paperwork. Hence, it is necessary that the managerial tasks are kept to a minimum level, i.e. "lean".

Participation. The development and operation of scientific facilities and systems are usually performed in participative environments, i.e. all project and systems engineers and designers are expected to contribute actively to managerial tasks such as gathering requirements from customers or users, conducting risk analyses, planning and scheduling, reporting progress, etc.

Modularity. openSE is intended to cope with systems engineering requirements of a wide variety of projects. Projects may not need to implement all the features. Hence, the openSE framework is designed to allow that some components can be implemented, while some others be left aside.

Scalability. Finally, openSE is equally scalable from large-scale scientific facility projects[2] to equipment development or upgrade projects[3]. While the focus is placed on complex projects, openSE is designed in such a way that it is applicable to other types of projects of varying levels of complexity.

openSE vs. other frameworks

openSE was not intended to reinvent practices or definitions when they already exist. openSE is widely inspired from practices of NASA (NASA's *Systems Engineering Handbook* [24]), ESA (ECSS Standards, [17]) or from the HERMES Swiss project management methodology [37].

Who contributed to openSE ?

Since openSE is an outcome of the PURESAFE Initial Training Network FP7 Marie Curie Actions project that is supported by the European Commission, most of the contributors come from the eight partners of this project, namely the two *case providers*: CERN in Switzerland and GSI in Germany; the three academic partners: KIT in Karlsruhe, Germany, TUT in Tampere, Finland and UPM in Madrid, Spain; and the three industrial partners: bgator in Tampere, Finland, SenseTrix in Helsinki, Finland and Oxford Technologies Ltd. in Abingdon, U.K.

openSE raised interest outside the core of PURESAFE project community. Participants from ESS in Lund, Sweden, from Université de Savoie, Annecy, France, from Arts & Métiers ParisTech, Paris, France, from École Centrale Paris, France and from LAAS-CNRS, Toulouse, France also took part in this editorial initiative. Moreover, a few master students from Université de Lausanne, Switzerland, from the Norwegian University of Science and Tech-

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[2] Such as the LHC in operations since 2008 at CERN, Geneva, Switzerland, or FAIR under development at GSI, Darmstadt, Germany.

[3] Such as the development of new superconducting magnets, accelerating cavities, collimators or remote handling devices.

nology in Trondheim, Norway and from Conservatoire National des Arts & Métiers, Paris, France have also contributed.

The openSE editorial project relied on the following participants:

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Laurent Tabourot
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Helmut Weick
Thijs Wijnands
Martin Winkler.

Who can benefit from openSE ?

openSE is intended to three overlapping groups of users:

- Programme and project managers and coordinators, project and systems engineers and designers, programme and project management professionals (planners, schedulers, controllers, analysts, auditors) involved with programmes and projects related to scientific facilities or systems subject to ionizing radiation such as the LHC (Large Hadron Collider) at CERN, Geneva or FAIR (Facility for Antiproton and Ion Research) at GSI, Darmstadt.

- Programme and project managers and coordinators, project and systems engineers and designers, programme and project management professionals involved with programmes and projects related to complex facilities or systems subject to ionizing radiation e.g. nuclear power plants, or in programmes and projects related to complex systems subject to various hazards e.g. space related projects; and more broadly to anyone involved in ETO-, BTO- or MTO-based projects[4].
- Students in engineering, applied physics or in project management who wish to better understand systems engineering; instructors and lecturers in these fields.

How is openSE structured?

The openSE framework consists of several editorial components:

- The present **booklet** that is made of four chapters.

  Chapter I describes the basic concepts used in the openSE framework starting with the definition of what is a project and more specifically what are projects handled in the context of large-scale scientific facilities emitting ionizing radiations. This chapter also provides insights on what project management and systems engineering are, both the general and in that particular context. The rationale behind some of the concepts and definitions of openSE is also given in this first chapter.

  Chapter II describes the openSE lifecycle and how it shall be used.

  Chapter III provides an understanding and definitions of roles and corresponding responsibilities in an openSE-based project context.

  The last chapter, chapter IV, is dedicated to a description of key processes, including their key deliverables, which are mainly key project management or systems engineering documents.
- Several **guidelines** which are stand-alone documents that describe more procedurally one or a few steps of a key process, including the tools that can be used. Almost all guidelines describe these key processes with three levels of difficulty to accommodate the varying experience level of the project participants. The **simple approach** is intended to small systems projects or to newcomers to systems engineering; The **intermediate approach** is suitable for the rather complex systems projects and those project participants who have achieved a certain level of experience and

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[4] ETO = engineer-to-order, BTO = build-to-order, MTO = make-to-order, that are supply approaches suited for highly configured products.

want to implement more elaborate solutions. Finally, the **advanced approach** provides insights to those project participants who are very accustomed to systems engineering and want to implement state-of-the-art practices and tools. For further reading, references to books or to scientific papers are proposed at the end of each guideline.

- Several **specifications** that cover project management aspects (cost estimate figures, standard document contents and templates, handbooks and guidelines, etc.) or engineering aspects (standard designs, interfaces, material, engineering procedures, manufacturing or assembly procedures, verification and validation typical plans and procedures, benchmark data, etc.).
- A few **case studies** that document examples of development projects that have followed (or have been reengineered to follow) the openSE approach. Cases are offered with a few levels of complexity from entry level to advanced level implementations.
- So-called **toolbox brochures** that complement guidelines to provide or describe tools such as software, that may be useful for an effective implementation of a process.
- Finally, a **poster** and a **pocket guide** that are aimed at easing the dissemination of openSE .

To ease their retrieval, guidelines, specification and toolbox brochures are organized in three series:

- A **project management** (**PM**) series grouping all brochures addressing project management practices, that can also be found in documents such as PMI's *Project Management Body of Knowledge* [31] or textbooks such as that of Meredith & Mantel [25] or of Pinto [30] ;
- A **systems engineering** (**SE**) series of brochures addressing general engineering and new product development practices that can be found in documents or textbooks such as NASA's *Systems Engineering Handbook* [24], ESA's ECSS standards [17] or Sage & Rouse's *Handbook of Systems Engineering and Management* [35];
- A **remote engineering** (**RE**) series for all brochures featuring solutions and standards in the telerobotics and remote handling domains.

The list of guidelines, specifications, toolbox brochures is expected evolve continuously. The reader is therefore invited to visit regularly the openSE website (`openSE.org`) to consult this list and download the latest material available.

Acknowledgements

The PURESAFE project participants and the openSE editorial project participants express their thanks to the European Commission which, by means of its FP7 Marie Curie Actions funding, under grant agreement no. 264336, allowed the creation and release of openSE .

Chapter I

openSE Foundations

The first chapter is aimed at providing foundations to the openSE framework. It includes the key concepts associated to this framework and the rationale to some editorial choices.

I.1. Programs, Projects and Activities

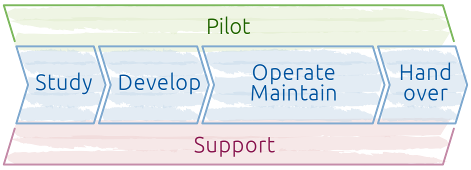

Figure I.1. Activities performed in any organization.

Activities performed in particle physics laboratories are similar to those run in any other organizations, whether they are privately owned, such as industrial firms, or from the public sector. Figure I.1 gives a breakdown of these activities which are basically of three types. Those directly related to the **core activities** of the organization (in blue) that consist of performing studies, developing projects, operating and maintaining facilities, systems and equipment, and then getting rid of them (i.e. decommissioning). They are overlaid by **pilot activities** that provide the input for strategic and tactical decision making and planning of the core activities. The core and pilot activities are supplemented by **support activities** that provide administrative, organizational and technical support to the pilot and core activities. All these *activities* are drawn as arrows because they are progressing as the time goes on.

Projects can be found almost everywhere in such a conceptual activity model. Studies and development projects are projects by their essence, as are decommissioning activities. But projects can also be found at the pilot, operation and maintenance and support levels: the refurbishing of an organizational structure to accommodate a new development project is also a project; consolidating or upgrading a system or equipment that is under operation is also a project, as well as important and sensitive corrective maintenance action after a failure.

Projects can be seen at several levels: the design and development of a new accelerator is necessarily a project, but also the design and development of its dipole magnets[1] for instance. Lifecycles similar to that of Figure I.1 can be observed at various "systems depths". This understanding is sometimes referred to as the "fractal approach to project management": projects can typically be made of sub-projects that to some extent are also projects [38].

Even if some professional associations such as the Project Management Institute aim at homogenizing practices, the project management corpus differs substantially depending on the professional field it is applied to. This necessary scalability is for instance referred to as "tailoring" by the HERMES project management methodology. One can typically observe different approaches for the eight following domains, with also different levels of project management maturity: computing and ICT (information and communication technologies), construction and civil engineering, process industry, new products, new services, organizational projects, events and training and HR (human resource) development (see Figure I.2).

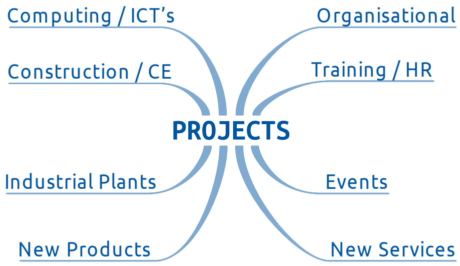

Figure I.2. A typology of projects.

Research projects shall be considered separately as they do not completely fulfil all of the generally agreed definitions for projects in organizations. So-called scientific projects differ from research projects in the sense that the former are aimed at providing means for performing research projects. In many research domains, scientific projects share many of the characteristics of industrial projects. This is the case for particle accelerator facilities that have many engineering aspects in common with process industry facilities, such as chemical plants or power stations.

While "mid-size" projects belong typically to one of the eight domains mentioned above, large-scale scientific projects are composed of sub-projects from all eight domains. Taking the CERN's Large Hadron Collider (LHC)

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[1] Major equipment of any circular accelerator that aims at bending particle beams to keep them on a given trajectory.

as an example, its conception and development involved sub-projects from these eight domains:

Organizational projects. The launch of this unprecedented large-scale project required an enormous organizational effort: before 1996, CERN's organizational structure was designed to accommodate the Proton Synchrotron (PS), the Super Proton-Synchrotron (SPS) and the Large Electron-Positron Collider (LEP) particle accelerator operations requirements. The approval of the LHC Project led CERN Management to review the organizational structure in order to facilitate the realization of this project. CERN moved from a functional organizational structure to a matrix organizational one.

Construction. The LHC required the construction of several new civil engineering works: huge underground caverns, kilometres of underground tunnels, and industrial and tertiary surface buildings. To succeed with these subprojects, the civil engineers wanted to legitimately implement state of the art practices in construction project management.

New products. The manufacture and assembly of some 1600 cryomagnets for instance, required the implementation of enhanced plant engineering and operations management practices.

Industrial plants. The several cryogenics facilities that were constructed to deliver liquid nitrogen and liquid helium to the superconducting cryomagnets and accelerating cavities have a lot in common with industrial plants, and cryogenics engineers are used to following project management practices from this project domain. So did and do the thermal and electrical engineers for the construction of the cooling plants and power distribution stations respectively.

Computing and ICT. The development of the many controls required to operate an accelerator relies predominantly on information systems project management practices: for instance, software engineers prefer agile project management methodologies such as Scrum.

New services. In a modern management understanding, a particle accelerator facility aims at delivering a service to the particle physics community: to enhance this objective, new service development project management practices were followed.

Training and HR. The conception, development and construction of the LHC Project required the redeployment of many technicians, engineers and physicists as well as the recruitment of many project specialists. The success of these human-resource deployment and development projects were possible because appropriate project management practices were implemented.

Events. Last but not least, it is not possible to succeed with these large-scale projects if they are not appropriately marketed. In April 2008, the LHC Open Days welcomed ca. 80 000 visitors. The success of such an event is subject to the implementation of best project management practices suited to event projects.

These eight domains shall cover all types of projects that may exist in an organization, or at least in a scientific organization such as CERN or GSI. What about complex systems development projects? They are somewhere in between industrial plant development projects and new product development projects. They are somehow one-of-a-kind products, even if they are manufactured in small series production, and in this regard they shall benefit from project management practices used in industrial plant development projects. Because they can be built in small to medium series, practices from new product development projects, e.g. those promoted by Ulrich and Eppinger [36] for instance, shall also be referred to in openSE .

With respect to projects and activities to consider, openSE is primarily focused on projects with a technical scope and outcome, whether it is a facility, systems or equipment. The openSE framework is not primarily meant for computing/ICT projects or organizational projects. Because scientific facility projects cover several project domains (civil works, industrial plants, series produced components, controls, etc.), openSE is general enough to accommodate these specificities. But because equipment development is very much focused on complex systems, openSE provides means to enable an efficient and effective management of these development projects.

I.2. Specificities of Scientific Projects

While the previous section gives a brief overview of the activities and projects in particle physics laboratories, on their scope and complexity, this second section focuses on some specificities of the development projects run in this context, be they of organizational or technical nature, or even of both. Some of these specificities are shared with other scientific projects, or with projects in the field of aerospace for instance.

First of all, most of the time, scientific projects are their own prototype. They are one-of-a-kind projects , whose aim is to get the best scientific and technical outcome, and preferably even “better-than-best”. This has a direct consequence on their functional requirements: they are evolving whilst the project progresses. The aim is to get the best possible performance, sometimes leading to delay some technical decisions to the very last moment in order to get a range of solutions that are as wide as possible, while decisions are delayed as late as possible.

The second specificity is linked to and is somehow a consequence of the previous one: the final users—i.e. the scientific scholars—are taking an active part in the development effort, and most of the time even leading the projects. In addition, the sharing of tasks within a multiple organizations framework, such as the high-energy physics collaborations [12], is becoming increasingly common: the collaborative design and development effort is spread around tens or hundreds of teams, whose tasks need to be coordinated. This of course has various consequences not only at the organizational, but also at the technical level.

A third point is the question of lifetime of such facilities. Given the sometimes rather huge financial effort of such big science projects, there is a request for a lifetime of several tens of years. For instance, the CERN Proton Synchrotron came into operations in 1959, and is still one of the key elements of the injection chain of the Large Hadron Collider. This requires that not only the further evolutions and upgrades be included in the design constraints and the configuration be carefully managed all along the lifecycle, but also sustainability is included in the key criteria.

One of the main points regarding sustainability is radiation damage. These projects lead to develop equipment emitting ionizing radiation, which implies that other equipment is subjected to artificial ionizing radiation. So all materials shall withstand radiation doses in order not to lose their functional capacities. The activation of equipment shall be kept as low as possible, in order not to jeopardize the further maintenance and upgrade activities.

Since these facilities emit ionizing radiation, they need to be shielded in order to minimize the level of radiation. Accessibility as well as radiation protection equipment add another layer of complexity to the design of the facility and equipment. Most of the time, they are based on “multi-physics” designs: not only mechanical, or electrical or electronics, but both, or even worse associating in a complex way mechanical, mechatronics, cryogenics, vacuum and radio-frequency components sometimes in the same assembly.

I.3. The ORAMS Trade-off

Almost all if not all facilities, systems or equipment development projects have Operability, Reliability, Availability, Maintainability and Safety (ORAMS) requirements. Out of the five ORAMS domains of performance, safety issues may impact the success of a project quite differently from the others; probably because of the way safety-related deliverables are assessed. While operability, reliability, availability or maintainability (ORAM) requirements are usually perceived as resource dependent by project contributors, the "safety success", i.e. the absence of accidents or to some extent the freedom of risk as defined in ISO 12100:2010 [22], is not necessarily perceived as such. While it is generally admitted that additional resources are likely to improve the ORAM performance of the developed object, it is also often perceived that such a principle is not straightforward with safety aspects. The probabilistic nature of safety shall be considered. Typically, if over its development and operations, there is no impact on people, no accident, no impact on the environment, then the project is considered a success. However, in terms of ORAM requirements, whose assessment is based on something happening, the "safety success" will not be seen because "nothing tangible" has happened. For this reason, stakeholders are usually keener to work out the ORAM side of the project rather than the safety side. As a result, the five ORAMS requirements should be addressed differently.

As exposed in the literature, systems engineering does not provide specific means to handle this issue. For instance, although NASA's *Systems Engineering Handbook* [24] suggests that safety reviews be organized regularly, out of the 33 typical activities of the Concept and Technology Development Phase of a space project, safety is only scarcely mentioned in two of them. Out of the 21 typical activities of the Preliminary Design and Technology Completion Phase, only one is related to safety. The situation is similar to that of ESA's ECSS standards [17]. According to ECSS-E-00A [18], safety is an activity that is part of product quality assurance. However, an ECSS standard is dedicated to safety, but not in the sense it is understood for scientific facilities and systems emitting ionizing radiations. Safety is also scarcely introduced in IEEE Std. 1233 [21]. Textbooks related to systems engineering are numerous. Of the few reviewed, all of them mention safety as an important requirement for the development of a complex system. For instance, Sage & Rouse [35] consider safety as part of the "scientific and engineering effort" of SE, as transverse activities beside "reliability, maintainability, survivability, human engineering, and other factors". It is also worth mentioning that none of the resources cited above introduces the two equivalent concepts of ALARA (As Low As Reasonably Achievable) or ALARP (As Low As Reasonably Practicable) related to radiation safety concepts that are of prime importance throughout the lifecycle of a particle accelerator facility.

I.4. Project Management and Systems Engineering

I.4.1. Project Management

The design, development and construction of large-scale scientific facilities rely on the appropriate use of project management practices. However, these practices are many and sometimes specific to certain aspects of the project. Forcing all project contributors to implement a unique project management approach must have a rationale. Sharing a common core is a prerequisite for enhancing communication and coordination among project participants, although the definition of this core is not straightforward. Some suggest the implementation of PMI's *Project Management Body of Knowledge* [31] that aims to describe project management practices suited to all types of projects. ISO 21500:2012 standard [23] "can be used by any type of organization, including public, private or community organizations, and for any type of project, irrespective of complexity, size and duration". But however, both documents are general-purpose standards and not sufficiently specific to fulfill the expectations mentioned above.

PM Standards

The *Project Management Body of Knowledge* [31] and the ISO 21500:2012 standard [23] are the two global standards in the field of project management. They both aim at homogenizing practices while not necessarily providing an approach for implementing project management on a given project.

PM Methodologies

Methodologies complement standards by providing processes which, if there are appropriately followed, shall efficiently facilitate the adherence to the parent standards. The PRINCE2 [32] and the HERMES [37] methodologies, from the UK and Switzerland respectively, are two examples of project management methodologies.

The PRINCE2 methodology addresses project management with four integrated elements: Principles, Themes, Processes and Project Environment. By conscious use of these elements, PRINCE2 can be applied to any kind of project. The method is recognized internationally and gives projects common systems, procedures and language.

The HERMES project management methodology proposes a phase-based, goal and results-oriented, and scalable approach to project management. Particular attention is paid to the specific roles and duties of all relevant participants. In the 70's, when this methodology was developed, its initiators were definitively willing to promote a project management framework facilitating the enhancement of transparency throughout the project development. The HERMES methodology has been reviewed each decade to take into account lessons learned.

I.4.2. Systems Engineering

According to the International Council on Systems Engineering (INCOSE)[2] "systems engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionalities early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem: performance, cost & schedule, manufacturing, testing, operations, training & support, and disposal". In other words, systems engineering can be seen as a subset of the project management corpus dedicated to the development of complex mechatronics systems embedding software.

According to NASA's *Systems Engineering Handbook* [24], but also to ESA's ECSS standards [17] and many systems engineering textbooks, particular attention shall be paid to needs[3] gathering and functional and non functional requirements definition, integration, verification and validation, solution finding and qualification.

Needs & Requirements

Needs gathering and requirements definition consist of identifying who the stakeholders are, what their intentions are towards the systems, then transforming these needs into a validated set of technical requirements expressed by means of "shall" statements .

Needs shall be expressed in "stakeholders' words", but a complex systems development project is likely to involve tens to hundreds of contributors who may not necessarily have consistent and coherent expectations. A project only expressed in "stakeholders' words" is impossible to coordinate.

Lessons learned have shown that expressing needs statements as "shall" requirements is a prerequisite to guarantee the success of a project. While needs can be expressed in a rather informal and vague manner to be endorsed by the stakeholders who have a holistic vision of the outcome of the project, but not necessarily an in-depth understanding of all the disciplines involved in the proposed concepts, they are insufficiently precise to ease

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[2] See www.incose.org.

[3] Needs, users' requirements and stakeholders requirements a synonymous terms.

the coordination and integration of the many sub-systems. Requirement statements are derived from needs. Requirements translate in a straightforward way the expectations of the stakeholders. Since requirements shall be focused on the outcome of the development project, their identification is feasible only out of one or a few preferred concepts. The concepts are worked out and tuned until the list of requirements is stabilized and endorsed by the stakeholders.

Integration

Products or systems integration consists of transforming lower-level components into higher-level systems and making sure that the integrated systems function properly.

Verification & Validation

Products or systems verification and validation (V&V) are two processes that are not always described as such in all systems engineering standards or textbooks. Verification relates to the validated set of technical requirements by checking if the expected requirements are implemented and performed as expected. Validation relates to stakeholders expectations by checking if these expectations are fulfilled at overall system level.

V&V are important components of the V-Modell (see Figure I.3) and are two distinct process areas of the CMMI model[4] where “verification ensures that you are building a product according to its requirements, specifications, and standards. For verification, you should ask the following questions: ‘Are you meeting the specified requirements?’ ‘Are you building the product right?’ ”, while “validation ensures that your product will be usable once it is in its intended environment. For validation, you should ask the following questions: ‘Are you meeting the operational need?’ ‘Does this product meet its intended use in the intended environment?’ ‘Are you building the right product?’ ”

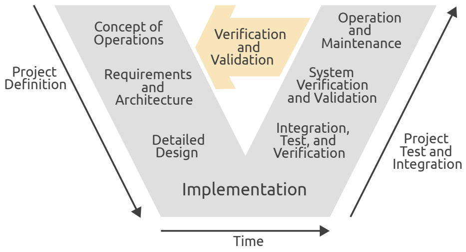

Figure I.3. The SE V-Modell.

Practically, while the development project is on-going, it is necessary to verify

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[4] See `www.cmmiinstitute.com`.

and validate the fulfillment of these needs and requirements. This is the purpose of the verification and validation activities, operationally supported by a Verification Plan and a Verification Report, and a Validation Plan and a Validation Report.

Solution Finding

Working out concepts that may fulfil needs is a process that overlaps both needs gathering and requirements definition. For complex systems, needs can be gathered, i.e., some kind of "needs portfolio" can be assembled, only if one already has some ideas of possible solutions. Concepts result from needs, but a certain conceptualization of possible solutions is required to gather needs exhaustively. Needs gathering and concept generation are two processes that are to be synchronized.

These three activities—needs gathering, solution finding and requirement writing—form the core of the project front-end phase. Even if they should be performed in a given sequence, these activities should be approached in a holistic way. With many scientific projects, the deliverable of this phase is called Conceptual Design Report (CDR).

I.4.3. Project Management vs. Systems Engineering

As suggested by PMI's *Project Management Body of Knowledge* [31], if appropriate attention is paid to the ten knowledge areas[5] of project management, typically by implementing the best suited management techniques, then project teams substantially increase the chance of success of their projects. Several academic studies confirmed that the implementation of standardized practices increases project success (see for instance Milosevic & Patanakul [26]). But other studies convey the contrary, such as that of Dvir, Raz & Shenhar [16]. To these authors: "The findings suggest that project success is insensitive to the level of implementation of management processes and procedures, which are readily supported by modern computerized tools and project management training. On the other hand, project success is positively correlated with the investment in requirements' definition and development of technical specifications". The SE corpus is somehow in line with this conclusion: it suggests that a particular attention be paid to the technical side of the project, especially during its early phases. Systems engineering shall complement project management practices by providing

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[5] These ten knowledge areas are: Project Integration Management, Project Scope Management, Project Time Management, Project Cost Management, Project Quality Management, Project Human Resource Management, Project Communications Management, Project Risk Management, Project Procurement Management, Project Stakeholders Management.

means to communicate and coordinate the technical dimension of the project. However, while systems engineering is particularly well suited for the conception and development of complex products that are made of subprojects of a mechatronics nature (mechanics, electronics, controls software), it has not been designed for complex facilities that will probably include civil engineering, process plants, new product/service developments, information and communication technologies. Both project management and systems engineering practices and standards provide insight on the processes to implement, including their lifecycle, on the stakeholders at large and their roles, and on the outcomes of the various processes, in particular the key documents to release.

I.4.4. Lean Management, Lean PM and Lean SE

The word “lean”, when used in the operations management context, refers to the absence of waste, such as waste of time, money, materials, etc. [20]. Whereas usual project management practices focus on completing projects on time and on budget while meeting the project objectives, lean project management and to some extent lean systems engineering focus on doing the same while using the minimum amount of time and resources while maintaining or even improving quality [29].

Traditional techniques usually focus on tools, techniques and methods. Lean management differs from this approach in the sense that its focus is more on creativity, change and continuous improvement. Lean management techniques are characterized by empowerment, fast delivery, elimination of waste and the dominance of holistic viewpoints. Lean management is particularly popular in commercial companies where the deliveries of product and services are based on the value chain. Eliminating the production of waste of any kind will obviously lead to more economical value being created. Another important aspect is the learning and the continuous improvement of the project teams, promoting the impact of professional development, elaborating on successful experiences, and encouraging quality idea generation.

I.5. Scientific Development Projects

Scientific facility development projects are probably most similar to industrial plant development projects that implement rather complex processes. Hence, the design and development of scientific facilities that emit ionizing radiation like particle accelerator facilities can find some similarity with nuclear power station or nuclear waste reprocessing plant projects. But even though if they might be similar on several aspects, they strongly diverge on some others, for instance:

- Nuclear power stations or nuclear waste reprocessing plants shall generate revenues for their owners, whereas most large-scale scientific facilities are not at all business-oriented. These two types of development projects balance differently the so-called “project triangle” (i.e., the trade-off between time, costs and performance to achieve Morris & Hough [28]). The performance perspective is definitively enhanced in scientific facility, systems or equipment projects.
- The number of engineering fields involved in designing and developing large-scale scientific facilities is most often larger than for nuclear power stations or nuclear waste reprocessing plants.

These aspects may not appear to be very selective, but in practice they are. Because of these specificities, scientific facility, systems and equipment development projects are approached differently.

Among the specific requirements are those of the nuclear licensing authorities. Even if nuclear material is not necessarily present in scientific facilities that are subject to ionizing radiation, national nuclear licensing authorities are consulted before these facilities are brought to operation. In order to provide their clearance, these authorities have specific expectations regarding safety: workers should not fall victims to an accident or professional illness because of the facility or system. This concern is covered by occupational health and safety. For the authorities, safety also encompasses integrity: the presence of the facility should not represent an unacceptable hazard to the people or the environment. It should operate reliably towards the teams in charge of construction, operation and maintenance. They typically require that a safety document be developed and endorsed. This so-called Safety Documentation [14] or Safety Data Package [24, 19] shall provide a comprehensive description of the facilities, but also justifications of all choices towards solutions enhancing safety and integrity—this includes the application of the ALARA approach—and specific prescriptions towards the operations teams so that the facility is operated safely and the integrity of the facility is guaranteed.

I.5.1. Collaborative Approach to PM and SE

Lessons learned show that the preferred project management approaches for scientific facility development projects result from the specificities of these projects. One key characteristic is that their many technological challenges need to be translated into an effort focused on the technical dimension of the project. As a consequence, the "project administration requirements" should never constitute a hindrance or get in the way of the scientists and engineers who already have the difficult task of finding innovative solutions to the myriad of problems brought about by their development [12]. For instance, for the LHC Project, less than two dozen people took turns to manage the project (the particle accelerator itself and the whole infrastructure) which involve tasks related to project planning and scheduling, cost control, risk monitoring, management of the configuration and technical information, throughout the 15 years of its design, development and construction. To meet this challenge, some strategic choices were made: for instance, an enhanced use of the Internet[6].

If the project management system of the LHC had to be summed up in a few key words, the adjectives "collaborative" and "participative" would certainly be the best suited. The idea was, therefore, to delegate a maximum of management tasks to the hundred so-called "project engineers", i.e., the many project managers in charge of sub-projects of this large-scale project. For instance, the electronic technical information management was put in place at the same time the project started in the mid 1990s. CERN was certainly avant-garde in its use of a "project management 2.0" system [13].

The expression "2.0" was attached to the word "Web" by Darcy DiNucci in January 1999 [15]. Her intention was to increase the simplicity and interactivity of the World Wide Web. Since, this expression has been attached to many concepts that show their authors' willingness to shift the reclusive practices of specialists to more collaborative approaches. "Project management 2.0" demonstrates this intention to give much more room to project contributors in planning exercises and notably project control, using as best as possible the functions of the World Wide Web. It should be underlined that "Web 2.0" has both its supporters and opponents. The latter denounce the anarchy and chaos within it [33], without omitting the "infobesity" that sometimes strains the acquisition of sought-after information.

This is why the project management approach used for the development and construction of the LHC integrates this willingness to allow key participants to actively take part in the process of progress reporting, but within a channelled framework in order to overcome the chaotic suffering of "Web 2.0".

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[6] It shall be recalled that the World Wide Web was developed at CERN at the end of the 1980s, initiated by an already globalized CERN scientific community, in response to information sharing problems.

I.5.2. Requirements from Licensing Authorities

As mentioned earlier, safety and integrity concerns are of prime importance in the conception, development and construction of scientific facilities, especially if they are expected to emit ionizing radiation. This applies to a facility when it is seen as a whole, but also equally to any of its sub-systems and components, whether they are developed in synchronization with the facility that they are part of, or afterwards in the frame of consolidation or upgrade projects. As a consequence, licensing authorities are very important partners in the process of preparing a facility or systems for operation and maintenance.

Even if they differ from one country to another, the expectations of the licensing authorities evolve and are still evolving as the global knowledge on nuclear and radiation safety management grows. Lessons learned from the operation of facilities on the one hand, and near-accident and accident inquiries and analyses on the other, contribute importantly to the evolution of these expectations. However, since the mid-1990s, the so-called ALARA (As Low As Reasonably Achievable) or ALARP (As Low As Reasonably Practicable) principle has become a major expected result.

To understand the ALARA principle, one should investigate the concept of risk. According to etymologists, the noun “risk” possibly has several origins. It might be traced back to classical Greek “$\rho\iota\zeta\alpha$”, that means “root” or to the ancient Latin “risicare” that means “reef” or “snag”. In both cases, Sabelli [34] suggests that this understanding typically led to the risk protection behaviour: one shall avoid the root on her/his pathway; the sailor shall protect her/his boat from grounding on a reef. The term “risk” can also be traced back to the Latin “rixa” that means “brawl” or “quarrel”. Sabelli explains that to survive or to protect their belongings, any one has to fight against others. These two possible etymologies clearly suggest that the concept of risk be understood from two opposite (antagonist) perspectives:

- The “risk-snag” perspective for which risk shall be cancelled or at least mitigated. This is typically the attitude safety engineers have had for many years;
- The “risk-action” perspective suggesting that any one shall take reasonable risks.

Undoubtedly, the advent of safety management rose to address the “risk-snag” perspective. Consequently, from a pure teleological viewpoint, a straightforward way for avoiding these “risk-snags” consists of getting rid of all the activities and systems that are at the origin of the risks. If this reasoning is pushed to the extreme, in other words getting rid of all activities and systems, then it becomes evident that this tenet is incompatible with the goal of any organization, which is creating value, or knowledge in the case of scientific institutions. The ALARA principle emerged from this necessity of mitigating "risk-snag" vs. "risk-action": how far can we pursue the goal of any organization while keeping safety risks under a tolerable level. With respect to ionizing radiations and their consequences on workers, the ALARA principle can be set up in terms of how much resource the organization accepts to spend to reduce the radiation risk towards its personnel and the population living in the area surrounding the facility.

In the field of radiation protection, the ALARA principle raised from experimental cell biology observations: when subject to ionizing radiations, human body cells absorb energy. Consequently, three processes may occur:

- If the deposited energy is low enough, the cells will repair themselves and no sanitary effects will be observed;
- If the level of transferred energy is too high, the cells will not survive the radiation and will die;
- In between, cell transformations are observed, but the boundary thresholds are very difficult to define and predict; in some situations some cells will repair, and some in others will die.

In addition, while the first and third processes are of a deterministic nature—in that the outcome can be predicted—, the second one is of a pure stochastic nature: it is difficult to predict the consequences of the radiation for the cells on the medium- or long-term. Because of this, it is impossible to define a radiation dose and a dose rate threshold below which there is undoubtedly no risk. Radiation protection experts suggest a trade-off approach that advocates the implementation of all possible protective and preventive measures, so that the radiation risk reaches a tolerable level in the spirit of the "risk-snag" vs. "risk-action" trade-off exposed before.

Practically, implementing the ALARA principle consists of foreseeing several solutions to perform an activity that substantially contributes to its value generation process, and to set up the most acceptable trade-off between the cost—but also time and quality—of implementing high-end solutions that definitively lower risks, and may be less costly—or quicker, or of lower quality—solutions that present certainly more risks but which are fully acceptable, i.e. well below tolerable risks and within legal provisions. For instance, remote-controlled interventions by means of telerobotics systems in ionizing radiation areas are necessarily seen as more expensive since they require more investment compared to more straightforward human interventions.

As ALARA is a globally accepted principle, licensing authorities have within their mission the duty to verify that all organizations that potentially generate risks for their personnel, for the surrounding local population and for the environment, implement this principle. As is often the case in matters of quality assurance, the organizations concerned shall provide evidence of appropriate implementation by providing the proper documentation of the processes followed. In this way, the safety documentation management process becomes important.

I.5.3. Organizing Safety

There is no definitive approach to organizing safety in an organization. Nevertheless, because safety and environmental concerns have taken a central position in the ethical behaviour of many organizations, it can be observed that, because the stakeholders are numerous (the management of the organizations, as well as members of their personnel, trade unions, local communities, local authorities, national authorities, etc.), organizations develop a “democratic behaviour” towards these concerns. The results of these observations are the emergence of the principles of Montesquieu. In *The Spirit of Laws* written more than two centuries ago [27], Montesquieu argues that the concept of democracy relies on the separation of power between the legislature who makes the laws, the executive who manages the community within the boundaries defined by the laws, and the judiciary who punishes those who do not respect the laws.

Translated into the safety-related vocabulary of organization, this means that by analogy:

- Organizations shall develop their own set of safety rules, based on international and national laws on the one hand, and on official and professional standards on the other hand;
- Any member of the personnel of the organization—and stakeholders at large—shall carry out their tasks in conformity with the safety rules;
- Organizations shall create their own inspection bodies to ensure that the safety rules are correctly implemented.

The implementation of safety measures is then the duty of everyone, and not a matter to be kept with safety experts. Since quality principles shall also apply to safety, everyone shall document safety to prove that the appropriate safety provisions have been considered and implemented.

I.5.4. Safety Documentation Management

Especially when the facilities and industrial processes are complex, featuring specialized technologies, the safety documentation that is expected has three purposes that lead to the three parts of the safety documentation:

- **Descriptive.** One part of the safety documentation shall describe succinctly the facility, systems, equipment, process, activity, etc., in words that can be understood by anyone having a general engineering knowledge. The questions to be answered in this descriptive part are typically: Why is it useful? Where is it located? What is it made of? How does it work? When will it be constructed, operated, dismantled? Who is responsible for its development, construction? How will it be developed, constructed? Who will be responsible for its operation, maintenance, dismantling? How will it be operated, maintained dismantled? And last but not least, which hazards are present in the facility/process?
- **Demonstrative.** The second part provides evidence that the safety provisions, either foreseen or implemented, either preventive or protective, either technical or organizational, are sufficient to avoid or mitigate the risks down to a tolerable level or even below. All the safety risks that have been identified and assessed are listed in this demonstrative part, including the corresponding risk analyses, the ALARA processes conducted, and the technical and organizational risk control measures.
- **Prescriptive.** The third part describes the safety rules to follow, and the technical and organizational provisions which need to be implemented to develop, construct, operate, maintain, and dismantle the facility, systems, and equipment. Practically, this part collects all the manuals, instructions, procedures and all other appropriate documents to conduct the tasks listed above, including the appropriate quality management framework.

Records, including monitoring data, lessons learned and improvement write-ups, may constitute the fourth part to the safety documentation.

The release of this documentation shall be synchronized with the facility lifecycle. During a study phase, this safety documentation may only consist of a preliminary descriptive part and of an initial demonstrative part. These components are important in the process of deciding whether or not to implement a project. The prescriptive part is prepared while the project is being developed. One part of the manuals, instructions and procedures is likely to be dedicated to the construction of the facility, systems or equipment. The rest addresses operations, maintenance and dismantling requirements. Finally, records and lessons learned are collected after safety reviews and inspections are launched.

I.5.5. Remote Engineering as a Response to ALARA

Some environments require remote techniques to be used because the radiation levels are far too high to envisage carrying out tasks using hands-on methods. An example of this is the use of a robot to carry out transfers of irradiated targets with contact dose rates of 1 Sv/h in CERN's ISOLDE facility. However, there are also tasks where radiation levels are in a range where human interventions can be considered. In these cases it is necessary to determine the most appropriate method of carrying out the work based on application of the ALARA principle.

Remote techniques offer the possibility of great reductions of radiation exposure, but, at the current state of maturity of robotic intervention solutions, due to their relative complexity, time to implement and costs, they are often considered as the last option when other attempts at optimizing a hands-on process to reduce radiation exposure have not produced acceptable results. When considering the way to carry out a handling process or intervention, the starting point will be to consider whether it could be carried out "hands-on." For the purposes of ALARA, it is first necessary to calculate the estimated radiation exposure if the task is carried out hands-on. Based on this estimate, a decision can be taken as to whether the radiation exposure is sufficiently low that no further optimization is necessary. If radiation exposure estimates are above the ALARA process initiation threshold then the next stage is to consider optimization options. For external exposure the optimization options to be considered are usually based on reducing exposure time, increasing distance and providing shielding. For internal exposure, responses may consist of wearing personal protective equipment, including breathing apparatus.

If the time of exposure can be reduced by speeding up the task—for example by modifying the items to be handled or tooling used—the resulting dose reduction may mean that hands-on work complies with ALARA requirements. If the distance between the person carrying out the work and the source of radiation can be increased by using extended tools—for example a long-reach radiation dose rate meter—then the ALARA requirements could be considered to be fulfilled.

Providing local shielding between the source of radiation and the person carrying out hands-on work could also reduce the exposure to acceptable levels; for example shielding is used to protect surgeons operating on patients who have been given radioactive tracers.

If these relatively simple optimization methods do not result in acceptable exposure levels then it is necessary to apply remote techniques. In effect remote techniques are an extension of the distance and shielding methods of exposure reduction—the time taken will usually increase but the distance and shielding advantages will far outweigh this aspect.

I.6. Integrating Radiation Safety Concerns with Systems Engineering

Scientific facilities are all complex systems, and the management of their design and development can definitively benefit from systems engineering practices. But to do so, it is necessary to embed radiation safety requirements in the systems engineering corpus. On the one hand, the V-Modell depicts well the systems engineering process (see Figure I.3). On the other hand, CERN's approach to safety documentation management for instance, fulfils expectations in matters of safety information handling. Prosaically, integrating radiation safety requirements as expected by all stakeholders of a scientific facility emitting ionizing radiations may consist of an overlap of these two concepts.

Since systems engineering practices complement project management ones by providing specific insights on need gathering, solutions finding and requirements writing, then on enforcing continuous verifications and validations, the issue becomes how radiation safety concerns can be combined with these systems engineering sub-processes.

I.6.1. During the Project Front-End Phase

Radiation safety concerns shall be fully integrated in the needs gathering exercise from the project front-end phase. Collecting needs consists of identifying stakeholders' expectations of the complex systems to develop, from several perspectives: technical needs (typically functions to fulfil, performance to achieve, interfaces to accommodate, technical feasibility); development needs (project feasibility, manufacturability, constructability); and operational needs (typically strategic alignment, economic feasibility, reliability, availability, maintainability). Collecting safety needs—including environment protection needs—is the fourth perspective.

To accommodate safety needs and requirements, the Conceptual Design Report (CDR) should at least dedicate a safety annex assembling preliminary descriptive and demonstrative parts. To make this annex consistent, some preliminary ALARA analyses may be needed.

I.6.2. During the Project Development Phase

For many scientific projects, the deliverable of the definition phase is called a Technical Design Report (TDR). As for the Conceptual Design Report, this document should have at least one annex dedicated to safety, complementing the descriptive and demonstrative parts of the Conceptual Design Report and featuring some elements of the prescriptive part. Additional or enhanced ALARA analyses are likely to be conducted during the definition phase and appended to the Technical Design Report. During this phase, remote handling and robotics options are typically considered and engineered.

I.7. Integrating Remote Engineering Concerns with Systems Engineering

I.7.1. During the Project Front-End Phase

During the project front-end phase the aim should be to consider as many options as possible before narrowing down to the option selected for the development phase. Typically there will be many alternative approaches that can be considered to solve problems related to processes or interventions in radioactive areas.

Once an initial ALARA evaluation has shown that a fully hands-on approach will not be acceptable, then it is necessary to consider optimized and remote techniques. In scientific facilities a process or intervention may combine a mixture of hands-on, optimized and fully remote techniques for different stages (or sub-tasks) of a process or an intervention.

For the purposes of this explanation we will consider that a process or an intervention has been broken down into sub-tasks and the explanations below will apply to a sub-task that may or may not form part of a larger series of tasks.

The standard systems engineering phases and processes of needs gathering, requirements definition, etc. will apply. This section covers the particularities linked to remote techniques. As remote handling is generally more demanding than remote inspection or remote measurement, this section describes only the considerations related to remote handling. Consequently, some aspects may not need to be considered for remote inspection or measurement.

The following are things to consider when defining the task requirements:

- Radiation issues—dose rates, contamination;
- What is to be handled and its characteristics such as size, weight, fragility;
- The movements to be made—are these straightforward and compatible with a crane or not;
- The space in which it is to be handled;
- The precision with which it needs to be handled;
- Interfaces of the component with adjacent components and supports;
- Lifting and handling points;
- The level of dexterity required—could include degrees of freedom, applied forces;
- The number of times the operations will need to be carried out;
- The distances to be covered to reach the area where the operation will be carried out;
- Access issues—are there local obstructions making it difficult to get access to the component to be handled?
- Vision issues—is the component easily visible from several points of view?
- Time restrictions;
- Fragility of the surrounding environment;
- Environment—heat, presence of chemicals, presence of water, etc.

Once the task requirements are defined, the option of hands-on intervention should be evaluated—as a benchmark for further iterations in the generation and evaluation of options. If hands-on is not acceptable, then it is time to consider how handling can be optimized. This should ideally start with a brainstorming phase where different ideas are proposed. These ideas will include the time, distance and shielding approaches. This phase may also consider changes to the components to be handled, and the infrastructure as well as the handling operations themselves. If simple optimization techniques are not sufficient for ALARA, then remote techniques will need to be used.

Once the decision has been reached that a remote system is necessary, the following issues need to be considered:

- Viewing using windows or cameras;
- Teleoperation or automatic operations;
- Shielding;
- Recovery from breakdown;
- Maintenance;
- Access for maintenance or recovery;
- Risk of failure—safest to assume it will fail;
- Power—electrical or hydraulic actuation;
- Who will operate;
- Who will maintain;
- Buy or build in-house;
- What is available on the market;
- What has been done before at other similar facilities;
- Radiation tolerance issues for equipment.

Based on the above considerations, a few conceptual design ideas should be produced along with an investigation of key technical feasibility and cost issues. Ideas could range from remotely controlled crane to a pair of force reflection telemanipulators mounted on a transport device, or a fully automated robotic system in a shielded containment with sophisticated ventilation system.

The pros and cons of the different ideas then need to be evaluated. Ideally a minimum of two proposals should be presented to a Project Board in order to get a formal go-ahead to investigate one solution.

The final output of the front-end stage should be a Conceptual Design Report for validation. This should include a risk and recovery analysis, cost and time estimates for implementation and may be supported by selected mock-up test results.

I.7.2. During the Project Development Phase

Once the conceptual design, cost and schedule estimates have been agreed at the end of the project front-end phase the development phase can start.

Here, standard systems engineering will apply with several added considerations related to the particular problems associated with remote engineering.

These include:

- Multi discipline systems—mechanical electrical, hydraulic electronic, communication and software;
- The need to ensure the design of the facility is optimized for remote handling;
- The need to react to changes in the facility that may arise during the development phase;
- The prototype nature of these systems—typically having a large amount of one-off design;
- The need for the systems to be operational for many years—technology will be out of date and not supported, know-how lost due to staff changes;
- The problems associated with radiation and contamination—tolerance issues and implications for access in the event of a breakdown or maintenance;
- The vital importance of having recovery methods after breakdown;
- Radiation issues during installation;
- Impact of malfunction on the surrounding facility;
- Decommissioning and disposal of radioactive equipment at the end of its life. These issues taken together generate a need for:
- A range of technical specialists to cover the disciplines involved;
- Extensive commissioning, recovery and maintenance trials—preferably in a mock up;
- Full documentation;
- Good communication with other teams working on the rest of the facility to ensure compatibility.

Chapter II

The openSE Lifecycle

II.1. What is a Lifecycle?

It seems that the concept of lifecycle first appeared in the marketing domain in the early 1960's. At that time, it was focused on the various phases of the life of a commercial product, from its development, through its market introduction, its market growth, its maturity, to its decline and withdrawal. Less than one decade later, this concept has been extended to the life of projects. Most if not all of the project management-related standards and methodologies propose a prototypical lifecycle.

Typically, a lifecycle, whether it is designed to enhance the understanding of a project or of something else, is made of phases and of decision points . These latter are found either between the consecutive phases or directly within them.

When associated with a project management or systems engineering methodology, the lifecycle also aims at providing a common vocabulary so that project stakeholders have a common understanding of the project flow, from its initiation to its completion.

Finally, one shall keep in mind that a lifecycle, as a model, is necessarily a simplification of reality. For instance, phases are drawn to take place one after the other in a strict sequential way. The reality is always more complex and includes overlaps, rework, etc.

II.2. The openSE Lifecycle

The openSE lifecycle is definitely inspired from various lifecycle models[1] one can find in the literature, but adapted to practices one can encounter in scientific facilities. Contrary to a few proposed project lifecycles that are expressed in a rather complicated way, the decision was taken to rely on a rather simple model.

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[1] It is especially inspired from the lifecycle that supports the HERMES 4 HERMES [37] project management methodology.

II.2.1. The Facility Lifecycle

Figure II.1. The lifecycle.

The openSE lifecycle is a linear **phase-gate** model featuring six project phases (in blue on Figure II.1), augmented by two “macro-phases”, namely the **Operate & Maintain** macro-phase (in green) and the **Decommission** macro-phase (in red). At that point, and in somehow a fractal approach to project lifecycle, these two macro-phases are partially (Operate & Maintain) and fully (Decommission) made of projects: upgrade, consolidation, repair[2] and decommissioning projects. These projects should in turn be broken down into the six project phases of the openSE lifecycle.

II.2.2. The Inter-Phase Decision Points

Figure II.2. Decision points.

The openSE phases are separated by gates called **decision points**. These decision points are of five types: one is an ignition point; two are used to steer the flow between the six project phases; the two remaining are used to handle the end of the Operate & Maintain and Decommission phases respectively.

- The **lightning flash** that is at the starting point of the lifecycle, refers to the existence of a problem or of a need that should be addressed in a project mode. The associated decisions are “go” or “no go”.
- The **traffic light** in a rhomb features an inter-phase “**go-nogo**” **decision**. Such a decision type occurs at the end of the Initialize phase for launching or not the Study phase, and at the end of the Study phase to launch or not the Design phase, i.e. the development project itself.
- The **ship wheel** in a rhomb features a drift decision . Such a decision type occurs at the end of each of the project development phases, namely the Design, Build and Commission phases.

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[2] Major preventive or corrective maintenance activities or initiatives may benefit from being managed in a project mode, i.e. by means of the six project phases, and not my means of a simple set of work orders.

- The **stop hand-signal** in an octagon is not a project-related decision, but a facility-, systems- or equipment-related decision. It simply refers to the decision to stop operating (and by the way maintaining) the facility, systems or equipment.
- The **recycle sign** in a circle reflects that the facility, systems or equipment do not exist anymore.

II.2.3. The Six Project Phases

The six phases of the openSE development lifecycle are namely the **Initialize**, **Study**, **Design**, **Build**, **Commission** and **Finalize** phases (see Figure II.3).

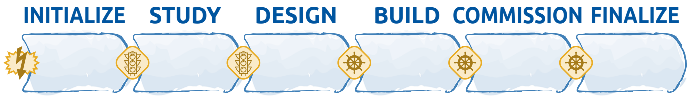

Figure II.3. The development phases of the lifecycle.

Initialize. This first phase has three key goals:

- Analyzing the present situation and defining what is the "**problem**" to solve;
- Proposing a few possible solution to the problem;
- Formalizing the decision to perform the project, at least to launch the project front-end phase.

The key deliverables of this phase are the Project Proposal that after being endorsed by a Project Board may become the Project Roadmap (see [2] and Chapter IV).

Study. This second phase has four key goals:

- Gathering the **needs**, i.e. the users' requirements or the stakeholders' requirements;
- Converting the gathered needs into **requirements**;
- Identifying all possible **solutions** to the problem;
- Proposing one solution, i.e. the preferred solution, and demonstrating its **feasibility**.

The key deliverable of this phase is the Conceptual Design Report (see Chapter IV).

Design. This third phase has five key goals:

- Finalizing the definition of the needs;
- Finalizing the list of requirements accordingly;
- Designing the solution, i.e. performing the engineering design, also called the basic design or the systems-level design;
- Planning further the Build and Commission phases;
- If required, developing prototypes, proofs-of-concepts, mock-ups.

The key deliverable of this phase is the Technical Design Report (see Chapter IV).

Build. This fourth phase has three key goals:

- Performing the detailed design;
- *Materializing* the equipment, systems and, by the way, the facility; practically, this consists of procuring, manufacturing, assembling, installing, etc.;
- Verifying the conformity of the *materialization*, i.e. controlling that all the requirements have been correctly implemented.

Several tasks of this phase have physical assets as deliverables. For quality assurance purposes, the key deliverable of this phase is the As-Built Documentation that comprises the Detailed Design Documentation and the Verification Reports (see Chapter IV).

Commission. This phase has five key goals:

- Validating the outcome(s) of the project, i.e. demonstrating that all the users' requirements or the stakeholders' requirements are satisfied;
- Refining, i.e. getting rid of all the minor and not fully solved problems encountered during the previous phases, and ramping-up, i.e. launching the operation of the facility, of the systems or of the equipment with the aim of reaching the targeted performance level;
- If required, adapting the project to the evolving context to accommodate emerging needs from users or stakeholders, to implement new technologies, to reposition the project outcome with respect to *competitors*' facilities, systems or equipments, etc.;
- Training the users (operations teams, maintenance teams);

- Releasing Operations & Maintenance Documentation.

The key deliverables of this phase are the Validation Reports and the Operations & Maintenance Documentation (see Chapter IV).

Finalize. This last phase has just one goal: capitalizing the lessons learned all along the project front-end and development phases. The key deliverable of this phase is the Close-out Report (see Chapter IV).

II.2.4. Tailoring of the Project Phases

Under certain circumstances or for the sake of simplicity, it may be wise to skip one or a few phases, or to merge two or three consecutive ones together. One shall keep in mind that phases are somehow "autonomy periods" during which the Project Team has the duty to perform the required tasks so that the expected deliverables can be released and used for the inter-phases decision processes.

This tailorization may particularly be suited to:

- small systems or equipment projects, or sub-projects, or prototype, proof-of-concept or mock-up development projects where the Design, Build and Commission phases can be merged.
- development initiatives for which the solution to the problem is well known and for which the Study phase can be skipped.

II.3. The Reticular and Fractal Natures of the openSE Lifecycle

Figure II.4 (page 30) attempts to show that project phases are not necessarily fully sequential. The move from one phase to the other assumes that all the expectations from the previous phases are achieved. But quite often it may not be the case. Because the progress of a subsequent phase can feed an *a priori* completed phase on the one hand, and in order not to delay unduly the progress of the project on the other hand, it can be wise to validate the start of a subsequent phase while the previous ones are not fully completed. Further work or rework may be required so that past phases are reviewed and their completion validated in light of the latest developments.

Figure II.4 also highlights the necessary fractal nature of all technical projects over a certain size. A scientific facility development project—or an upgrade project, or a consolidation project—is likely to be made of systems or equipment that have to be studied and developed by means of sub-projects.

Each of them can then be seen as a project made of all or part of the six project phases.

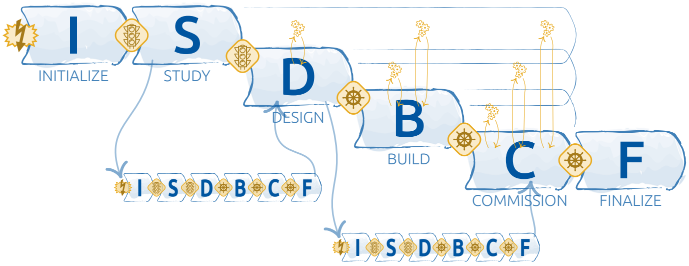

Figure II.4. The lifecycle in a fractal understanding.

Chapter III

openSE Roles and Responsibilities

III.1. Why Defining Roles?

Common sense but also many research works have shown that role definitions and clear responsibility sharing among the Project Stakeholders contribute to project success. Typically, methodologies such as PRINCE2 [32] or HERMES [37], pay a particular attention to this aspect.

III.2. The openSE Key Roles

Figure III.1 provides a visual repartition of the Key Project Stakeholders.

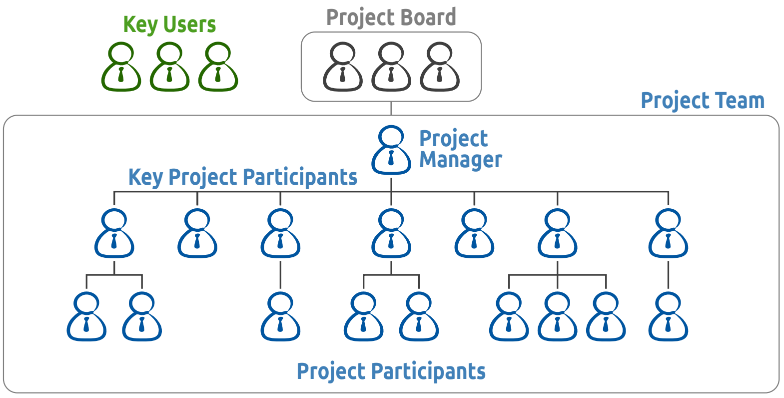

Figure III.1. The Key Project Stakeholders.

III.2.1. The Project Board

The body that governs the project is called the Project Board (**PB**). Its duties, inspired from the above mentioned HERMES project management methodology, are the following:

- Ensuring the strategic management of the project;
- Guaranteeing the acquisition and availability of resources, in importance and in due time;
- Because of the latter, being ultimately responsible for the successful completion of the project;
- Validating the gates between phases, but also within phases when such gates are considered;
- And, in case of conflict, arbitrating.

Project Board is the openSE preferred term. Alternative terms which have a similar definition exist and are: Strategic Board, Steering Board, Strategic Committee, Steering Committee, Project Owner, Product Owner, System(s) Owner, Project Sponsor.

An individual shall satisfy one of the following conditions to be a member of the Project Board of a project:

- to be a major resource provider to the project;
- to be in the supervision line of several Key Project Participants;
- to be a major beneficiary of the outcome of the project;
- to be importantly impacted by the outcome of the project.

Ideally, a Project Board should consist of three to six members. For large-scale projects, the membership may exceed 20 participants. The Project Manager is *de facto* member of the Project Board, but without decision voice. The Project Board may also decide to invite a few Key Project Participant such as the Technical Coordinator.

The Project Board is a body that shall hold regular meetings, at least for validating the completion of a phase prior to moving to to the next one. The Project Board may also decide to meet regularly while a phase is on-going; e.g. monthly, every second month or quarterly according to the size, complexity, challenges to take up and risks. Experiences have shown that the time gap in between these meetings should decrease as the project or phase progresses; e.g. from quarterly to monthly, or from monthly to weekly.

Information related to the Project Board (its membership, its organization, etc.) shall be given in the Project Management Plan (section 2.1 of the PMP; see [3]).

III.2.2. The Key Users

End Users of the outcome of a project can be many. The Key Users form a subset of these End Users. The task of Key Users will typically consist of providing needs, i.e. users' requirements to the Project Team so that the preferred solution to the initial problem is likely to be the one expected from those who will be using the project deliverable(s).

For a scientific facility, systems or equipment, the Key Users shall be found among the members of operations teams or of the maintenance teams. In general, Key Users are experience operators or maintenance staff.

III.2.3. The Project Manager

The Project Manager (**PM**) is the person who is mandated by the Project Board to manage the project. Among his/her duties are:

- Ensuring the operational management of the project;
- Being responsible towards the project board for the organization of the project and its coordination.

Project Manager is the openSE preferred term. Alternative terms which have a similar definition exist and are: Project Leader, Project Coordinator, Project Director. The Project Manager is often seconded by a deputy.

III.2.4. The Project Team and the Project Participants

Project Team and Project Participants

The Project Team is the team formed with all the individuals mandated to participate to the project, either part-time or full-time, i.e. the Project Manager, the Key Project Participants and the other Project Participants.

Project Participant is the openSE preferred term. Alternative terms with a similar definition exist and are: Project (Team) Member, Project Contributor.

Key Project Participants

Key Project Participants are experts in a given technical or technological field who are asked to oversee Work Packages or Activities. Their responsibility includes the operational supervision of some Project Participants.

Key Project Participant is the openSE preferred term. Alternative terms with a similar definition exist and are: Lead (Project) Participant, Lead (Project) Member, Key (Project) Member, Lead (Project) Contributor, Key (Project) Contributor, Work Package Leader, Activity Leader, Work Package Holder, Activity Holder.

Working Groups

To address specific issues encountered as the project progresses, temporary Working Groups can be formed. It is the duty of Key Project Participants to convene such groups. The Working Group Convener can already be part of the Project Team, or is enrolled in the Project Team for that very purpose. Alternative name for this role are: Working Group Chairperson, Working Group Leader, Task Force Convener, Task Force Chairperson, Task Force Leader.

III.2.5. The Coordinators and Officers

Based on the size of the project, its complexity, the challenges to take up, the uncertainties of the project and of its environment, it may be wise to assign so-called "coordinators" or "officers" to handle specific coordination or managerial aspects of the project[1]. In general, they all are Key Project Participants.

Resource Coordinator

He/she is in charge of overlooking resource aspects associated with the project, whether these are human resources, financial resources, and to some extent in-kind contributions. If required, the Resource Coordinator may also have the duty to set up an earned value management system with the support of the Planning Officer. The Resource Coordinator is also the editor of the Project Reports. He/she is the editor of the sections related to resource and scope management of the Project Management Plan. Alternative names for this role are: (Project) Cost Manager, (Project) Cost Officer, (Project) Cost & EVM Manager, (Project) Cost & EVM Officer, Project Administrator.

Technical Coordinator

After the Project Manager, the Technical Coordinator has a really central role in a scientific facility or systems development project[2]. His/her duties consist of:

- Developing the appropriate Product Breakdown Structure;
- Ensuring consistency of the systems and equipment interfaces;
- Defining and maintaining the successive Technical Baselines of the project;

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[1] These coordinators and officers are called **functional managers** in the PMI's *Project Management Body of Knowledge* [31].

[2] For scientific equipment development projects, this role is usually undertaken by the Project Manager or his/her deputy.

- Developing and maintaining a Change Control System to monitor the configuration;
- Being the contact person with the Integration Design Office to ensure that all requirements are appropriately considered, especially for the infrastructures;
- Leading the verification and validation processes of key documents such as engineering specifications, engineering change requests, integration drawings, etc.;
- Ensuring the generation, the dissemination and the storage of the project information in the appropriate information databases;

If no one is assigned to specifically endorse the roles described here after, and upon request of the Project Manager, the Technical Coordinator may also undertake these roles. Alternative names for this role are: Lead (Project) Engineer, Chief (Project) Engineer, Systems Engineer, Integration (Project) Engineer, (Project) Integration Manager, Design Coordinator, Engineering Coordinator.

Installation Coordinator

In the context of a scientific facility or systems development project[3], he/she is in charge of overlooking all installation-related aspects of the project, including: logistic aspects (i.e. coordinating the design and procurement of transportation and handling means); worksite utility aspects (i.e. ensuring that water supply, energy and temporary lighting, communication networks, sewage, etc. are available); installation sequence aspects with the support of the Planning Officer(s) or acting as Planning Officer; installation safety aspects with the support of the Safety Officer(s) or acting as Safety Officer. Alternative names for this role are: Installation Manager, Construction Manager, (Project) Field Manager, (Project) Worksite Manager.

Commissioning Coordinator

In the context of a scientific facility or systems development project, he/she is in charge of overlooking all commissioning-related aspects of the project, including: precommissioning and commissioning sequence aspects in coordination with the Installation Coordinator and with the support of the Planning Officer(s) or acting as Planning Officer; commissioning safety and facility and systems integrity aspects with the support of the Safety Officer(s)

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[3] This role does not exist for an equipment development project.

or acting as Safety Officer. Alternative names for this role are: Commissioning Manager, Lead Commissioning Engineer.

Planning Officer

The Planning Officer is in charge of preparing and keeping up-to-date the project Work Breakdown Structure (WBS), the Master Schedule and the Coordination Schedule(s) of the project. If some activities are performed by external contractors or contributors, he/she also has the duty to ensure that their Work Breakdown Structures and schedules are consistent with the Coordination Schedule(s) and by the way the Master Schedule. He/she is the editor of the sections related to scope and time management of the Project Management Plan and the provider of schedule-related material to the Project Reports. Alternative names for this role are: Chief Planner, Lead Planner, Chief Scheduler, Lead Scheduler, Schedule Manager, Schedule Officer.

Configuration Officer

The Configuration Officer is in charge of managing the configuration of the project's deliverable(s), whether these are a facility, systems or equipment. This duty includes:

- Providing support to the Technical Coordinator in preparing and keeping up-to-date the Product Breakdown Structure of the project and defining and maintaining the successive Technical Baselines;
- On the behalf of the Technical Coordinator, organizing the verification and validation processes of key documents such as Engineering Specifications, Engineering Change Records, integration drawings, etc.;
- In coordination with the organization's coding service, defining coding rules and providing codes to the various objects that need to be identified by means of a code;
- On the behalf of the Technical Coordinator and in coordination with the organization's engineering information management service, ensuring the generation, the dissemination and the storage of the project information (documents, 3D-mockups, 2D-drawings, data) in the appropriate information databases.

He/she is the editor of the sections related to the configuration management and coding conventions of the Project Management Plan. Alternative names for this role are: (Project) Configuration Engineer, (Project) Configuration Manager.

Quality Officer

The Quality Officer is in charge of managing the quality aspects of the project. This responsibility includes:

- Implementing and keeping up-to-date a Quality Management System suited to the specificities of the project, i.e. being the editor of the Project Management Plan and the associated processes and procedures, conventions, guidelines and document templates;
- With the input of Key Project Participants and especially the Safety Officer and Radiation Protection Officer, identifying and keeping an up-to-date list of applicable standards;
- Providing support to the Project Participants in the implementation of the appropriate quality procedures (typically the document release processes or the tracking of non conforming products);
- Being the project's contact person towards the IT support team(s) in charge of CAE/CAD[4] and PDM/PLM[5] information systems;
- Organizing quality audits, to ensure that quality processes and procedures are followed.

Alternative names for this role are: (Project) Quality Engineer, (Project) Quality Manager.

Risk Officer

The Risk Officer is in charge of managing the risks of the project, whether they are threats or opportunities. This responsibility includes:

- Together with the Project Manager, setting up the risk management strategy to be pursued;
- Being the editor of the project's Risk Register, duty that more practically consists of identifying all the risks that may affect, adversely or not, the performance of the project, assessing their importance, and together with the Project Manager and Key Project Participants, defining mitigation, avoidance, transfer or acceptance responses;
- If required, providing support to Key Project Participants to edit and release Project Continuity Plans.

He/she is the editor of the section related to risk management of the Project Management Plan and the provider of risk-related material to the Project

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[4] Computer Aided Engineering/Computer Aided Design

[5] Product Data Management/Product Lifecycle Management

Reports. Alternative names for this role are: (Project) Risk Engineer, (Project) Risk Manager.

Safety Officer

The Safety Officer is in charge of overlooking all safety-related aspects of the project on the one hand, and of the facility, systems or equipment on the other hand. Among his/her duties:

- Identifying and keeping up-to-date the list of applicable rules and standards in matter of safety (occupational and health safety, systems integrity, operations safety, environment protection);
- Being the editor of the Safety Documentation;
- Being the coordinator of safety on the worksite and in the workshops;
- Providing support to all Project Participants as soon as safety is concerned;
- Being the project's contact person towards the safety authorities and inspectors, and towards contractors and contributors for matters related to safety.
- Organizing safety audits, to ensure that safety processes and procedures are followed.

He/she is the editor of the section related to safety management of the Project Management Plan and the provider of safety-related material to the Project Reports. Alternative names for this role are: (Project) HSE[6] Engineer, (Project) HSE Coordinator, (Project) Safety Engineer, (Project) Safety Coordinator.

Radiation Protection Officer

He/she is in charge of overlooking all radiation protection and radiation safety-related aspects of the project and of the facility, systems or equipment. Among his/her duties:

- Identifying and keeping up-to-date the list of applicable rules and standards in matter of radiation protection and radiation safety;
- Being the editor of the radiation protection and radiation safety sections of the Safety Documentation;
- Performing radiation risk analyses, by means of simulation packages especially;

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[6] HSE stands for Health, Safety and Environment.

- Providing support to all Project Participants as soon as radiation protection and radiation safety are concerned;
- Being the project's contact person towards the radiation safety authorities and inspectors, and towards contractors and contributors for all matters related to radiation protection and radiation safety;

He/she is the editor of the section related to radiation protection and radiation safety management of the Project Management Plan and, if required, the provider of radiation protection and radiation safety-related material to the Project Reports. Alternative names for this role are: (Project) RP[7] Physicist, (Project) RP Expert.

III.3. The Project Stakeholders

Project Stakeholders are everyone who has interest with the project and is not part of the project team. So, among the project stakeholders are:

- The Project Board and the members of the Project Board;
- The organization's executives, managers of organizational units and external partners that provide resources to the project, either financial resources, manpower or in-kind contributions;
- Program and portfolio managers, if they are not already part of the Project Board, for projects that are part of the programs and portfolios they manage;
- Key Users and End Users of the project deliverable(s);
- HSE authority, inspectors and officers at organization level;
- Radiation safety authority, inspectors and officers at organization level.

Specific review, survey, audit or inspection bodies and their members are not considered to be among the stakeholders of the project, and nor are the suppliers and contractors.

III.4. The Project Initiators

Project Initiators are individuals, in general senior staff of the organization, who see a need or a problem, and who take the initiative to develop a Project Proposal and to submit it to a "foreseen or tentative Project Board". If endorsed by a Project Board, the Project Proposal becomes a Project Roadmap and the project is launched.

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[7] HSE stands for Radiation Protection.

Chapter IV

openSE Processes and Deliverables

IV.1. Why Define Processes and Deliverables?

Because a project is defined as an endeavour necessarily involving several participants, it is obvious that, for the sake of effectiveness, they all work in a coordinated way. This effectiveness will partially be brought by the Master Schedule and the Coordination Schedule, but both project management documents, when presented as Gantt charts, focus on activities and present the development of the project in a deterministic and linear way without considering uncertainty, decision processes, interactions or possible rework. Several authors have attempted to feature some of these concepts in graphical representations, but the results of these attempts did not really convince project practitioners. However, decisions are fundamental components of any managerial models, since Processes are means for describing in a generic way sequences of activities triggered by decisions.

Even if the number of promoters of a systemic approach to project management is growing, a proven key principle of effective project management consists of adopting a cartesian approach to breakdown the final deliverable into sub-deliverables and the project into activities. It follows that any project is made of activities where the completion of antecedent activities triggers the start of subsequent ones. But this networked sequence supposes that the outcome of an antecedent activity is a prerequisite to the start of the immediate subsequent ones. A clear understanding of what are the outcomes of an activity, i.e. its deliverables, contributes importantly to project effectiveness.

Deliverables are of two natures[1]: **physical deliverables**, i.e. pieces of equipment, elements of infrastructure, software, etc. and **informational deliverables**, i.e. documents, 3D-mockups, 2D-drawings, data. Of course, the first

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[1] At least those of some usefulness for the management of a project.

ones are fundamental, but their quality and especially their ORAMS aspects importantly rely on the quality of the latter. By deliverable, one shall understand “informational deliverable”. Physical deliverables are referred to as components, assets, equipment, systems or facility.

IV.2. Processes and Deliverables

The openSE processes and deliverables can be seen from three perspectives:

- The **project management** perspective, i.e. the set of project management-related processes that shall be performed to ensure the smooth planning and scheduling, and then the smooth development of the project. These processes are supported by the preparation and release of a few key project management documents;
- The **technical** perspective, i.e. the set of engineering-focus processes that shall be performed to describe accurately the technical solution to develop, and then the one that has been developed. This includes the preparation and release of the engineering documentation, including 3D-mockups and 2D-drawings, but also the to-build and as-built documentation as well as the operation and maintenance ones;
- The **safety** perspective, i.e. the set of processes that shall be followed to ensure that appropriate safety and integrity levels are achieved. These processes are supported by the preparation and release of the Safety Documentation.

IV.3. Key Project Management Deliverables

In a lean spirit, four types of project management documents shall be released in order to ensure a smooth planning and follow-up of the project (see Figure III.1).

IV.3.1. Project Proposal/Roadmap

The Project Proposal is the unique deliverable of the Initialize phase. This document becomes the Project Roadmap after the Project Board has decided to go ahead with the project. This is the same text that serves as a basis for the two documents. The Project Roadmap is just augmented with the decisional elements from the Project Board.

The Initialize phase is the step that pushes a need, a problem or an idea into a formalized project, or at least a duly acknowledge study. It is started

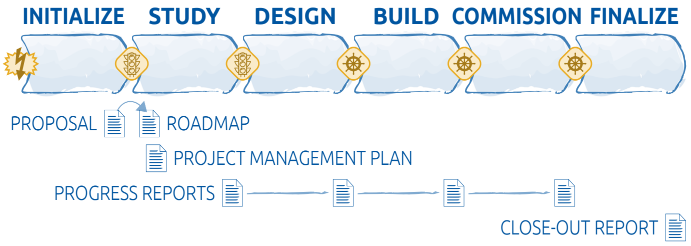

Figure IV.1. The key project management deliverables.

rather informally by the Project Initiators who translate the need, problem, idea into a Project Proposal. This document is then submitted to a "tentative Project Board" who may transform it into the Project Roadmap for the project.

The three pools of stakeholders involved are:

- The Project Initiators, who, from a quality point of view have the mission to author the Project Proposal but also to verify it before it is sent to the "approached or tentative Project Board";
- The "tentative Project Board" who shall decide for the remainder of the initiative;
- The designated Project Team and Project Stakeholders who are recipients of this Project Roadmap and who will have the duty to *implement* it.

When the Project Proposal is submitted to the "tentative Project Board", three options are possible:

- Either the Project Proposal is insufficiently elaborated, or the "tentative Project Board" considers themselves not legitimate to make the decision; in this case the Project Initiators are invited to rework their document and resubmit it, to the same panel or to another one;
- The "tentative Project Board" considers themselves legitimate, but they may also consider that the need is a "no-need", the problem is a "no-problem" or the idea is a "no-idea", and rejects the Project Proposal. The Project Initiators are informed and the project development process stops at this embryonic point;
- The "tentative Project Board" considers itself legitimate; the Project Proposal is validated as such, or planned to be validated after complements

and corrections are considered, and the Project Board converts it into a Project Roadmap.

In summary: the Project Proposal is authored and verified by Project Initiators. Once validated by a Project Board, it straightforwardly becomes a Project Roadmap[2].

The typical content of this very first project management document is the following:

Section 1. Problem Statement and Goal. In this section, the problem(s) or need(s) that are at the origin of the project are recalled; the rationale and justification are also provided. A description and an analysis of the present situation can also be provided.

Section 2. Possible Solutions. It is very likely that there are several solutions to a problem or ways to satisfy a need. This section aims at surveying the several possible solutions that may be considered and at highlighting the preferred one—or the very few ones—that may be the best answer to the problem(s) and/or need(s) and for which a particular attention should be paid in the next phase for evaluating its effective opportunity and feasibility.

Section 3. Preferred Solution. In this third section, the preferred solution is further described to provide some more tangible arguments to decision makers—the "tentative Project Board"—to go ahead with the development of the project. The sub-sectioning can typically be:

- **3.1.** Description of the preferred solution(s);
- **3.2.** Identification of stakeholders and *project sponsors*;
- **3.3.** Project phasing, planning and organization;
- **3.4.** Project costing and funding requirements;
- **3.5.** Benefits, i.e. return on investment, created by the preferred solution.

Section 4. Consequences and Risk Assessment. The decision to go ahead with the project shall be risk-based. This section shall provide means to appraise the consequences of not performing the project on the one hand, and on the other hand shall list the key risks that may jeopardize the project and its outcome(s) and shall identify responses to avoid, mitigate or transfer these risks.

IV.3.2. Project Management Plan

The Project Management Plan shall be the first deliverable of the Study phase. This document is typically drafted by the Project Manager (or by an editorial

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[2] A validated Project Proposal is necessarily a Project Roadmap.

team staffed with the Project Manager and some Key Project Participants) and released at the early stage of the Study phase. It is then refreshed and complemented at least at the beginning of every new phase, and whenever needed as the project progresses.

The aim of the Project Management Plan is twofold:

- giving the Project Board the assurance that the project expectations are well understood and that everything is done to ensure the operational success of the project;
- being sure that the Project Participants agree upon and share a common framework for organizing their project.

While the Project Board releases the Project Roadmap, the Project Management Plan is released by the Project Manager and sent to the Project Stakeholders for information. If a member of the Project Board feels that this document is insufficiently mature to ensure the operational success of the project, then they may ask the Project Manager to review and improve this document.

In summary: the Project Management Plan is authored by the Project Manager or a team made of Key Project Participants led by the Project Manager. It is verified by a few other Key Project Participants. It is validated by the Project Manager.

The typical content of a Project Management Plan is the following:

Section 1. Overview. This section is a brief reformulation of the Project Roadmap: the project purpose(s) and objectives are recalled and reformulated, the key milestones and deliverables are listed, as well as the assumptions, dependencies and constraints that may influence the completion of the project from the three usual perspectives: scope, schedule and budget. All key documents that are of prime importance to understand what are the project expectations are referenced in this first section.

Section 2. Project Organization. The membership of the Project Board is given in this section, as well as that of the Project Team and its organization: name of the Project Manager, Key Project Participants and other Project Participants. When applicable, all potential Project Stakeholders (e.g. Key Users and End Users of the project deliverables) may also be listed in this second section.

Section 3. Project Management Processes. The third section aims at providing insights on the various managerial processes that are to be implementing for insuring a smooth development of the project (those of PMI's *Project Management Body of Knowledge* [31] for instance).

IV.3.3. Progress Reports and Close-out Report

The third category of project management documents are the Project Reports and the Close-out Report. At least one report shall be released at the end of each phase, or as featured in the Project Management Plan. For phases which are exceeding six months, it is wise to consider releasing intermediate Project Reports. It is not necessary that these intermediate reports are as detailed as end-of-phase reports; a synthetic EVM-based report, complemented by a version of the Master Schedule featuring an isochrone line may be sufficient. Professional practices have shown that it is not necessary that these intermediate reports are spread regularly (e.g. every four weeks) over the phase; they can be relaxed in the first half of the phase and released more frequently as the phase reaches its end.

The typical content of an **intermediate Project Report** is the following:

Section 1. Major Achievements. This section lists in a rather narrative way the major achievements since last intermediate report. A list of the documents released during the reporting period can usefully be appended to this section.

Section 2. Problems Encountered. This section lists in a narrative way the problems that have arisen since last intermediate report and what are the responses found, under implementation or implemented to address these problems.

Section 3. Cost & Schedule. While sections 1 and 2 look at the technical progress, this third section looks at actual vs. planned figures from both the resource and time perspectives. The resource status can be given in the form of a table featuring the budgets and the actuals. The time status can be drawn as an isochrone line on the Master Schedule (or on a summary Coordination Schedule). Presenting these resource and time statuses aggregated in an EVM report, i.e. featuring the earned value (EV) w.r.t. the planned value (PV) on the one hand, and the earned value w.r.t. the actual costs (AC) can be worthwhile for decision makers.

Section 4. Work Laying Ahead. In a few sentences or a concise bullet list, this section provides a summary of the key tasks to be performed till the next intermediate report is released. A particular insight is given on critical tasks.

Section 5. Risks. To ease risk-based decision making, a “differential Risk Register” can be provided under this section, i.e. the list of risks whose assessments have evolved (appeared, increased, decreased or disappeared).

The content of an **end-of-phase Project Report** is similar to that of the intermediate report; it is typically the following:

Section 1. Major Achievements. This section lists in an aggregated way the Work Packages that were performed during the phase and their corresponding key physical outcomes and deliverables.

Section 2. Problems Encountered. The content of this section is similar to section 2 of an intermediate report.

Section 3. Cost & Schedule. The content of this section is similar to section 3 of an intermediate report.

Section 4. Risks. This section consists of the updated Risk Register.

If at the end of a phase it appears necessary to review the scope of the project, its allocated resources, its schedule, etc., this requirement may be conveyed in the conclusion. But these changes to the baseline shall be featured in an updated version of the Project Proposal, to be submitted to the Project Board for validation.

If several intermediate reports were released, these reports (document ID's and versions, titles and repository locations) can advantageously be listed in Project Reports.

Just as it is important to formally initiate a project, it is also important to successfully close it. The value of having a planned project finalized is in leveraging all of the information and experience gathered throughout the project. If the outcomes and deliverables are delivered and the Project Team immediately disbands, the opportunity to wrap up the loose ends, to document key learnings or to ensure that outcomes and deliverables are appropriately transitioned to the Operations & Maintenance Teams is lost.

Whereas the Project Management Plan is the entry point to all the project information while the project is under study or under development, the **Close-out Report** becomes the focal point to anyone searching information on the project, its outcomes and deliverables, and lessons learned. The typical content of this report is the following:

Section 1. Rationale. This section recalls the problem(s), need(s) or idea(s) that were at the origin of the project. This section may also describe how these problem(s), need(s) or idea(s) evolved as the project progressed and how the Project Team accommodated these evolutions.

Section 2. Achievements. This section lists in an aggregated way the Work Packages that were performed and their corresponding physical outcomes and deliverables.

Section 3. Risks & Issues The aim of this section is to recall what were the risks identified and assessed at the early stage of the project, what were those which appeared (recorded as issues in the course of the project), how the Project Team behaved when they appeared, and how they were addressed to avoid or mitigate their impact.

Section 4. Cost & Schedule. This section provides details on the initial project budget, on its evolution and on the actual costs with respect to the allocated budgets. It also provides details on the schedules: what are the actual Master Schedule and Coordination Schedule(s) with respect to the initial and successive baselined ones. These final resource and time statuses can advantageously be complemented by a final EVM report if such a reporting mechanism was implemented.

Section 5. Lessons Learned. This summary section is aimed to the attention of those who will have to conduct a similar project or that are in the course of initiating one. The purpose of this section is to provide tuition to prevent having the problems encountered on the completed project reappearing endlessly on future ones. Its content should result from a discussion held amongst the Key Project Participants at least, aiming at setting out the key learnings. The lessons learned should present equally what went well and what did not work, and be augmented by recommendations from the Project Team to the future Project Teams.

IV.3.4. Engineering Change Records

Engineering Change Records are aimed at triggering the changes of configuration as technical or programmatic problems occur in the Design, Build and Commission phases of the project, so that the required modifications are correctly reflected in the baseline documentation on the one hand, and on the physical components in the other hand.

The engineering change mechanism shall not be set-up during the Study phase. The reasons are obvious: a certain level of creativity is required and some kind of engineering administration could impair the required creativity. Then, such a mechanism is useful when changes can have financial consequences on components that are partly designed or built. This shall not be the case during a Study phase where no components are expected to be procured or made, except some prototypes. Finally, the main technical deliverable of the Study phase is the Conceptual Design Report. If the Project Team decides to implement an efficient editorial versioning mechanism for this document, then Engineering Change Records are useless.

It shall be noted that there are two processes affecting the configuration: the engineering change process and the non-conformity handling process.

IV.3.5. Other Project Management Documents

There are a few other project management documents that may be useful, even essential. They have not been listed in the key project management documents described above on purpose. Indeed, according to the size of the project and for the sake of leanness, they can advantageously be embedded in the Project Roadmap and the Project Management Plan. But as the size of the project grows, these documents become essential and a particular attention shall be paid to their preparation and release.

These additional key project management documents are the following:

Work Breakdown Structure

The WBS is both a document and a useful tool to define in a systematic way all the tasks to carry out—i.e. the so-called Work Packages—so that when they are all completed, of course in a defined sequence, the project deliverables are produced. Good practices suggest that the WBS is presented as a deliverable-oriented hierarchical decomposition where the *leaves of the tree* are the Work Packages to be performed by the Project Participants.

Work Package Descriptions

For projects of a certain size, it may be wise and useful to describe further each Work Package identified by means of the Work Breakdown Structure . The WBS is then complemented by Work Package Descriptions, as many as there are Work Packages. This document (one to two pages per Work Package) provides in a tabular way a title, a short narrative description of the work to perform, a list of deliverables, the budget allocated to it, a list of resources (manpower, means, cash) required to perform the work, and the key milestones.

Project Budget

This document details the resources (manpower, means, cash) made available by the *resource providers* (the organization, partners, funding agencies, etc.) and validated by the Project Board for the whole project, resources to be used for defined purposes. This document may provide various breakdowns: budget split by type of resources, by phase, by month, by quarter, according to the WBS, etc. If a Project Management Reserve is set, it is detailed in this document.

Master Schedule and Coordination Schedule

Schedules, presented in the form of Gantt charts, provide temporal information on the start and finish dates of the *tasks* to perform. The Master Schedule aims at communicating, in a concise way[3] the phasing of the project, down to macro-activities. It is of a strategic nature and primarily to the attention of the outside Project Stakeholders. It is not necessarily produced by means of a dedicated project planning and scheduling software.

The Coordination Schedule is much more tactical. It is typically produced using an analytical approach such as the Precedence Diagramming Method that is embedded in almost all, if not all, project planning and scheduling software; because of it, the critical activities and the critical paths can be highlighted. The Coordination Schedule is based on elementary tasks, that may be Work Packages or tasks at a finer decomposition level.

RACI Matrix

This document is a two-dimensional matrix featuring vertically the Work Packages, horizontally the resources—at least the Project Participants—and mapping the resources to the activities.

This document is known to be especially useful in clarifying roles and responsibilities.

Risk Register

This document lists in a tabular way all the identified risks that may affect the good course of the project and provides an assessment of these risks in term of probability of occurrence and impact, on both the performance—including all ORAMS aspects—, the resources and the schedule. It is also expected that the Project Team details which are the foreseen responses to these risks in term of avoidance, mitigation or transfer. Only the risks whose level is low might be free of response. In addition, Project Continuity Plans can be attached to the Risk Register to detail what to do in case of a given risk occurring.

IV.4. Key Technical Deliverables

While project management documents provide insights on the project organization (scope of the project, tasks to perform, allocated resources, deliverables, timescale), the technical documents provide a detailed description of the outcome of the project and guarantee that this outcome will perform as expected. The tasks—and the corresponding deliverables—that consists of gathering the needs, working out concepts and translating the needs in technical but also ORAMS requirements are assimilated to technical documents. The key technical are shown in Figure IV.2.

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[3] A Master Schedule shall fit on one A4-page or one overhead presentation slide.

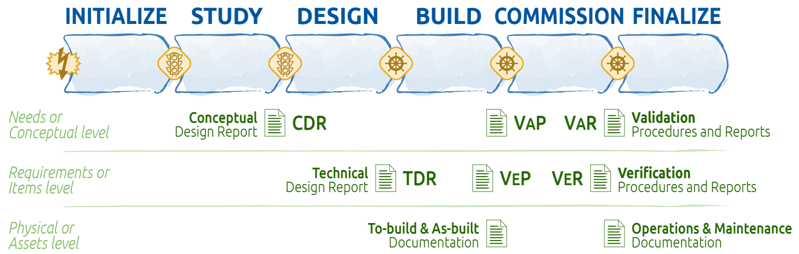

Figure IV.2. The key technical deliverables.

Technical documents belong to three families of documents, namely the documents that describe the project outcome:

- at **need** or **concept** level, i.e. **top level**;
- at **requirement** or **item** level, i.e. **intermediate level**;
- at **physical** or **asset** level, i.e. **detailed level**.

Top level documents are produced either at the early stages of the project, during the Initialize phase or at the latest stages of the project, during the Commission phase. Intermediate level documents are mainly produced during the Design phase a few of them are also released during the Commission phase. Detailed level documents are mainly produced during the Build phase of the project.

IV.4.1. Conceptual Design Report

It is the first key technical deliverable of the project released at the end of the Initialize phase. The purpose of this document is fourfold:

- Collecting the **needs** as they have been expressed by the Project Stakeholders, resulting from the needs gathering exercise;
- Listing briefly the **possible solutions** that may meet the gathered needs;
- Describing more precisely the **preferred solution**;
- Setting the functional and non-functional **requirements** that are a translation of the needs, but expressed in more formal and objective terms.

The decision to move from the Study phase to the next phase is triggered by this document. The CDR shall demonstrate the appropriateness of the preferred solution and its feasibility in terms of:

- Opportunity: the preferred solution matches the needs of the Project Stakeholders;
- Technical feasibility: the preferred solution is technically feasible, including ORAMS aspects and legal and administrative constraints;
- Temporal feasibility: the preliminary schedule accommodates the temporal constraints imposed by the environment or expressed by the Project Stakeholders;
- Resource feasibility: the preferred solution is feasible with the resources that may be allocated to the project[4];

The Conceptual Design Report is authored and verified by the Key Project Participants and validated by the Project Manager before being submitted to the Project Board for assessment.

IV.4.2. Validation Plan and Report

The drafting and releasing of the Validation Plan and Validation Report are the processes that demonstrate to the Project Board and Project Stakeholders that the outcome(s) of the project are fully compliant with the needs expressed at the early stage of the project.

The Validation Plan is typically prepared while the physical outcomes of the project are being made. This document details the approach that is intended to be followed to demonstrate to the Project Board and Project Stakeholders that the final deliverable fully addresses the needs. This plan is prepared by the Project Manager and Key Project Participants and is submitted to the Project Board. It serves as a basis for moving from the Build phase to the Commission phase.

The Validation Report records the results of the realization of the Validation Plan implemented in the Commission phase. This report is prepared by the Project Team and is submitted to the Project Board and Project Stakeholders as the final deliverable of the Commission phase. The decision to consider the project successfully completed is generally based on the conclusion of this report.

IV.4.3. Technical Design Report

The Technical Design Report is the main deliverable of the Design phase. It belongs to the intermediate level family of technical documents because its

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[4] Alternative resource feasibility criteria: Return on Investment (ROI) greater than zero; positive Net Present Value (NPV).

focus is at requirement level. This document collects all the technical information that describes in a consistent way the expected physical outcome of the project. All technical aspects shall be described in this document.

It is likely that the engineering design is supported by the use of Computer Aided Design (CAD) and Computer Aided Engineering (CAE) tools. 3D-renderings, 2D-drawings as well as calculation notes shall be referred to in the TDR.

IV.4.4. Verification Plan and Reports

The Verification Plan(s) and Verification Report(s) are also documents that belong to the intermediate level family of technical documents. The drafting and releasing of these documents are the backbone of the processes that demonstrate that all the requirements are implemented as defined in the Conceptual Design Report and reaffirmed and complemented in the Technical Design Report.

The Verification Plan(s) detail the verification—sometimes called qualification—approaches that are planned. Good requirements engineering practices suggests that the verification approaches are of five types: destructive testing, non destructive testing, analyzing, inspecting and conducting reviews. The Verification Report(s) record the results of the realization of the verification program.

IV.4.5. To-Build and As-Built Documentation

The To-Build Documentation also called Detailed Design Documentation is prepared and released at the early stage of the Build phase. This documentation includes 3D-mockups of components, fabrication and assembly drawings, installation drawings, schematics, interface specifications, components specifications, fabrication and assembly procedures, installation procedures, etc. The To-Build Documentation belongs to the intermediate level family of technical documents because it describes items i.e. generic descriptions of components that may be built in several physical instances referred to as assets.

The Technical Design Report serves as a base for the preparation and release of the To-Build Documentation. Even if the drafting of this documentation can be initiated in Design phase, while the Technical Design Report is not validated by the Project Board, the first documents belonging the the To-Build Documentation can only be released after the TDR is duly validated. For resource and technical constraint reasons, the production of this documentation is necessarily staged. The staging of this detailed design work is triggered by the Coordination Schedule.

The As-Built Documentation consists mainly of fabrication, assembly and installation reports. This documentation belong to the detailed level family of technical documents because it provides information on assets that are built or supplied.

It is likely that complex systems or equipment are not built as they were foreseen, and during the Build phase they can be adapted or tuned so that at they behave as expected. These adaptations shall be traced and this is the purpose of the Non-Conformance Records, that are part of the As-Built Documentation, to collect these discrepancies with respect to the To-Build Documentation. These adaptations may also have an impact on other components, equipment or systems already built or to be built. Then it is the purpose of the engineering change mechanism, by means of the Engineering Change Records, to assess the consequences of these adaptations, to identify the actions required to restore a certain consistency, and to monitor their implementation.

IV.4.6. Operations and Maintenance Documentation

A project is not complete if the Operations & Maintenance Documentation is not fully released. This documentation consists of most of the To-Build and As-Built Documentation prepared in the Design and Build and it is complemented by Operations and Maintenance Procedures, Instructions and Manuals. It is good practice to welcome future O&M stakeholders in the Project Team to have this Operations & Maintenance Documentation documentation edited by those who will use it.

IV.5. Key Safety Deliverables

The key safety deliverables consist of Safety Documentation whose content is enriched synchronously with the progress of the project. The facility, systems or equipment Safety Documentation shall have achieved an appropriate level of completion at the end of each project phase as shown in Figure IV.2, to move from one phase to the other.

The Safety Documentation is typically composed of four parts: the descriptive part, the demonstrative part, the prescriptive part and safety-related records.

In the Study phase, only the first two parts are required to move to the Design phase. The prescriptive part is prepared and starts to be populated during the Design and Build phases.

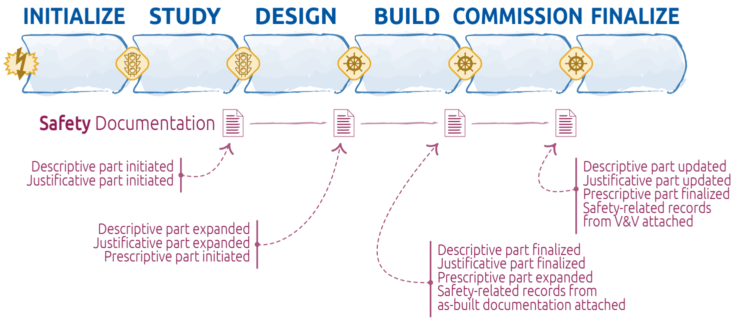

Figure IV.3. The key safety documentation deliverables.

IV.5.1. Descriptive Part

This first part of the Safety Documentation provides a description of the project outcome in terms of safety. The following aspects are developed:

- Brief description of the purpose(s) and motivations of the project;
- Location of the project outcome and other safety relevant features in the vicinity; interfaces with the surroundings and external systems;
- Description of the project outcome and of its main systems as relevant to overall safety aspects, in particular the description of safety systems and infrastructures associated to the safety of the project outcome; description of its operation and maintenance strategy;
- Description of the lifecycle of the project and of the outcome of the project;
- Provisions for dismantling the project outcome after its operations and maintenance period and for disposing of its components.

This part of the Safety Documentation shall be used as an entry point to the descriptive information related to the project outcome, i.e. schematics, drawings, technical notes, etc.

IV.5.2. Demonstrative Part

This section covers all safety aspects associated with the project outcome: occupational health and safety, facility integrity, operational safety and environmental protection. The second part makes the demonstration that all hazards and risks are identified, that all risks are assessed and that appropriate elimination or mitigation measures are taken.

This part of the Safety Documentation shall be used as an entry point to the demonstrative information related to the safety of the outcome of the project, e.g. Risk Register, risk analyses, etc.

IV.5.3. Prescriptive Part

The third part of the safety file shall compile the safety-relevant procedures required to operate and maintain the project outcome, to dismantle it and dispose of its components.

The procedures shall cover:

- Normal operation;
- Special operations: verification, validation, degraded mode operation;
- Maintenance;
- Special provisions to ensure the integrity of the project outcome;
- Incident management/remediation;

This part of the Safety Documentation shall be used as an entry point to the operational information related to the outcome of the project, e.g. all plans, manuals, procedures, and instructions concerning safety or safety-related activities.

IV.5.4. Safety-Related Records

The fourth part of the Safety Documentation shall gather temporarily or permanently:

- Records (safety and inspection reports, etc.);
- Lessons learned from the development, then from the operations, maintenance, and dismantling so that all those concerned can benefit from them;
- Engineering Change Records and Non-Conformance Records with incidences on safety, near-misses, incident and accident reports.

It also lists all the actions taken to continuously improve the level of safety of the project outcome.

Index

Bibliography

[1] The openSE editorial community (2014) *openSE Charter*, Geneva, Switzerland.

[2] ——— (2014) *Initiating a Complex Systems Project. Drafting and Releasing a Project Proposal/Roadmap*, Geneva, Switzerland. openSE Guidelines no. 1009.

[3] ——— (2014) *Setting up a Project Management System. Drafting and Releasing a Project Management Plan*, Geneva, Switzerland. openSE Guidelines no. 1000.

[4] ——— (2014) *Planning and Scheduling the Overall Project. Drafting and Releasing the Master Schedule*, Geneva, Switzerland. openSE Guidelines no. 1010.

[5] ——— (2014) *Costing the Project. Resource Estimating, Budgeting and Controlling*, Geneva, Switzerland. openSE Guidelines no. 1001.

[6] ——— (2014) *Constructing the Project Work Breakdown Structure*, Geneva, Switzerland. openSE Guidelines no. 1012.

[7] ——— (2014) *Constructing the Project RACI*, Geneva, Switzerland. openSE Guidelines no. 1005.

[8] ——— (2014) *Planning and Scheduling at Coordination Level*, Geneva, Switzerland. openSE Guidelines no. 1006.

[9] ——— (2014) *Managing Project Risks, Opportunities and Uncertainties*, Geneva, Switzerland. openSE Guidelines no. 1011.

[10] ——— (2014) *Coding and Versioning Project Documents*, Geneva, Switzerland. openSE Guidelines no. 1008.

[11] ——— (2014) *Controlling and Reporting the Progress of the Project*, Geneva, Switzerland. openSE Guidelines no. 1007.

[12] M. Boisot et al. (2011) *Collisions and Collaboration: The Organization of Learning in the ATLAS Experiment at the LHC.* Oxford University Press. 336 p. ISBN 0199567921.

[13] P. Bonnal. “Project Control 2.0.” *Revue Économique et Sociale* **70** (2), 2012. www.revue-res.ch.

[14] P. Bonnal, S. Weisz (2012) *Safety Documentation Management.* CERN, Geneva, Switzerland. 20 p. edms.cern.ch/document/1177755.

[15] D. DiNucci. “Fragmented Future.” *Print* **54** (3) 1999. pp. 32, 221?222.

[16] D. Dvir, T. Raz, and A. J. Shenhar. “An Empirical Analysis of the Relationship Between Project Planning and Project Success” *International Journal of Project Management* **21** (2) Feb. 2003. 89–95.

[17] European Co-ordination for Space Standardization (1993–) Series P (Policy) and M (Management) Standards. ECSS Secretariat, Requirements & Standards Division, Noordwijk, The Netherlands.

[18] ECSS-E-00A (1996) *Space Engineering: Policy and Principles.* ECSS Secretariat, Noordwijk, The Netherlands.

[19] ECSS-Q-40A (1996) *Space Product Assurance: Safety.* ECSS Secretariat, Noordwijk, The Netherlands.

[20] M. Holweg. “The Genealogy of Lean Production.” *Journal of Operations Management* **25** (2) March 2007, 420–437.

[21] IEEE 1233 (1998) *Guide for Developing System Requirements Specifications.* The Institute of Electrical & Electronics Engineers, Inc., New-York, NY, USA.

[22] ISO 12100:2010. *Safety of Machinery. General Principles for Design. Risk Assessment and Risk Reduction.* International Organization for Standardization, Geneva, Switzerland. 77 p.

[23] ISO 21500:2012. *Guidance on Project Management.* International Organization for Standardization, Geneva, Switzerland. 42 p.

[24] S. J. Kapurch (2007) *NASA Systems Engineering Handbook.* Washington, DC, USA: NASA Headquarters. 440 p. ISBN 9780471715375.

[25] J. R. Meredith, S. J. Mantel Jr. (2011) *Project Management: A Managerial Approach.* 8th ed., John Wiley & Sons. 600 p. ISBN 0470533021.

[26] D. Milosevic, P. Patanakul. “Standardized Project Management May Increase Development Projects Success.” *International Journal of Project Management* **23** (3) Apr. 2005. 181–192.

[27] Ch.-L. de Secondat, Baron de Montesquieu (1793) *The Spirit of Laws*, vol. 1. D. Niven, Glasgow, UK. ——— (1762) *The Spirit of Laws*, vol. 2. Donaldson & Reid, Edinburgh, UK.

[28] P. Morris, G. H. Hough (1988) *The Anatomy of Major Projects: A Study of the Reality of Project Management* John Wiley & Sons. 338 p. ISBN 0471915513.

[29] B. W. Oppenheim (2011) *Lean for Systems Engineering with Lean Enablers for Systems Engineering* John Wiley & Sons. 294 p. ISBN 1118063988.

[30] J. K. Pinto (1998) *The Project Management Institute Project Management Handbook.* John Wiley & Sons. 496 p. ISBN 0787940135.

[31] PMI Standard Committee (2008) *A guide to the project management body of knowledge.* 4th ed. Newton Square, PA: Project Management Institute. 403 p. ISBN 1933890517.

[32] OGC-UK (2009) *Managing Successful Projects with PRINCE2.* UK Office of Government Commerce, London, U.K. 342 p. ISBN 0113310595.

[33] E. S. Raymond (2001) *The Cathedral and the Bazaar.* O'Reilly. 258 p. ISBN 059655396X.

[34] F. Sabelli. "Les risques de l'économie, l'économie des risques: le point de vue de l'anthropologue." *7e Congrès de la Société Suisse de Management de Projet*, Lausanne, Suisse, 1999.

[35] A. P. Sage, W. B. Rouse (2009) *Handbook of Systems Engineering and Management.* 2nd ed., John Wiley & Sons. 1504 p. ISBN 0470083530.

[36] K. Ulrich, S. Eppinger (2011) *Product Design and Development.* 5th ed. McGraw-Hill/Irwin. 432 p. ISBN 0073404772.

[37] UPIC (2003) *HERMES Foundations. Management and Execution of Projects in Information and Communication Technologies.* Bern, Switzerland: Swiss Federal Strategy Unit for Information Technology (UPIC). 38 p.

[38] T. Williams (2002) *Modelling Complex Projects.* John Wiley & Sons. 288 p. ISBN 0471899453.