Programme Plan	
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Systems Engineering Management Plan

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1. INTRODUCTION

1.1 Purpose and scope

Because the future ESS facility is a system consisting of a huge numbers of interacting systems and contributors, it is considered crucial to implement a systematic approach to organize and to control the ESS implementation process from design to decommissioning [1]. Systems Engineering – SE - is an interdisciplinary approach and means to support the successful realization of such complex systems [2].

The need for Systems Engineering arose with the increase in complexity of systems and projects, in turn exponentially increasing the possibility of component friction, and therefore the reliability and safety of the design. When speaking in this context, the absence of a systematic and coordinated approach will also lead with a high probability to overheads and delays.

A coordinated approach allows a holistic view that enhances the quality of the system of interest and the configuration management during the implementation when change requests are unavoidable. In this view, it is mandatory to trace the expectations for a system at all relevant levels.

SE focuses on defining the user needs and the required functionalities early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem.

The ESS Systems Engineering Management Plan - SEMP - is intended to describe the technical processes, associated roles, products and tool features that will be used by the ESS team to support the construction programme.

The level of detail in the system descriptions to be developed has to be adapted in accordance with the impact of the failure of the system of interest (technical, licensing, organisational, financial, operational). This implies that the approach defined in this plan will have to be graded in accordance with a predetermined set of criteria to be identified. While this plan aims at detailing a comprehensive toolkit for conducting systems engineering activities during the ESS construction, the graded approach requires that participants focus their effort as sequenced below:

1. Requirements and verifications definition,
2. Integration of the safety in the design,
3. Integration of the operational aspects in the design.

The first stage is a prerequisite for establishing a solid foundation regarding the execution of the two latter stages.

The ESS Systems Engineering Management Plan execution will take benefit of all pre-existing initiatives to develop SE activities. Where the design is initiated, it is proposed to collect the expected performances and functions, to identify their interfaces and subsystems. Where the analysis of requirements is being performed, it is proposed to analyse and format the results of the process in order to make them compliant with the ESS generic approach developed in this SEMP. Throughout the SE process, the existing engineering documentation will populate consistently a structured technical configuration baseline while gaps will be identified.

Each pre-existing cross-functional working group will find in the SE framework a space in which they will enhance their interactions with other groups.

It is assumed that this customized approach will gradually lead all systems in a holistic perspective putting the design teams in a supplier-provider relationship which supports an unambiguous identification of the interfaces.

The SE process aims at integrating the technical risk and the safety aspect at all levels of abstraction of the design activities. In this respect, dedicated workshops will support the definition of safety requirements and the process will trace the required changes of the architecture for enhancing the system safety and mitigating the risk.

Throughout the SE process, a review process supports the assessment of any product for readiness to further development activities.

This SEMP is applicable to all technical tasks to be performed in support of the ESS construction programme [3]. This document will be placed under change control upon its initial release. The Systems Engineering Division – SED - will update the SEMP until the end of the construction phase.

1.2 Definitions, acronyms and abbreviations

Term	Definition
AFC	Administration and Finance Committee
BoM	Bill of Materials
CAD	Computer Aided Design
CB	Collaboration Board
CCB	Change Control Board
CDR	Critical Design Review
CEO	Chief Executive Officer
CMP	Configuration Management Plan
COTS	Commercial Off The Shelf
CSV	Comma Separated Values
DMS	Document Management System
DU	Design Update
EPG	ESS Project Group
ESS	European Spallation Source
FMECA	Failure Modes Effects and their Criticality Analysis
FTA	Fault Tree Analysis
FR	Functional Review
IDSD	Integration and Design Support Division
INCOSE	INternational Council On systems Engineering
LBS	Location Breakdown Structure
MBSE	Model Based systems Engineering
MTA	Maintenance Task Analysis
OMG	Object Management Group
PLM	Product Lifecycle Management
PM	Preventive Maintenance
PMO	Programme Management Office
PBS	Product Breakdown Structure
PHS&T	Packaging, Handling, Storage and Transportation
PSI	Paul Scherrer Institute
RAM	Reliability Availability Maintainability
RASEM	Requirement and Architecture Systems Engineer Manager
SAC	Scientific Advisory Committee
SAR	System Acceptance Review
SE	Systems Engineering
SED	Systems Engineering Division
SEM	Systems Engineering Manager

Term	Definition
SEMP	Systems Engineering Management Plan
SES	System Engineer for a ESS System
SET	Systems Engineering Team
SHE	Safety, Health and Environment
SNS	Spallation Neutron Source
SoI	System of Interest
STAP	Scientific and Technical Advisory Panels
System owner	Person responsible for the delivery of a verified system
TAC	Technical Advisory Committee
TBC	To Be Confirmed
TBD	To Be Determined
TBS	To Be Scheduled
TPM	Technical Performance Measure
TRR	Test Readiness Review
WBS	Work Breakdown Structure

1.3 References

[1] Systems Engineering Policy, ESS-0000967.

[2] IS0/IEC 15288:2008, System life cycle processes.

[3] Programme Plan for the European Spallation Source, ESS-0001122.

[4] Change Control Process, ESS-0001879.

[5] Design Process Specification, ESS-0002411.

[6] Configuration Management Plan, ESS-0003688.

[7] ISO/IEC WD4 42010 – Architecture Description.

[8] Requirement Development Guidelines, ESS-0003068.

[9] Radiation Safety Assessment at ESS, ESS-0000050.

[10] Risk Management Process, ESS-0000263.

[11] T-book, Reliability Data of Components in Nordic Nuclear Power Plants, 6th Edition, Studvik AB.

[12] Change Control Process, ESS-0001879.

[13] OMG Systems Modeling Language, Version 1.2, http://www.omg.org/spec/SysML/1.2/.

[14] http://europeanspallationsource.se

2. ESS OVERVIEW

2.1 ESS basic objectives

The basic objectives for the ESS facility are to provide world leading neutron scattering methods for European science, striving for scientific excellence and highest performance in terms of scientific results. The facility is in all its parts designed to meet these objectives and to satisfy European demand for both cutting edge capability and research capacity. In meeting these objectives, the ESS will provide new knowledge unattainable with other facilities or methods and strengthen science and underpin innovation in Europe.

2.2 ESS scientific scope

ESS will have a unique ability to study a broad range of structures and time scales due to its long, high-intensity neutron pulses. ESS will offer neutron beams of unparalleled brightness, delivering more neutrons than the world's most powerful reactor-based neutron source, and higher peak intensity than any existing spallation source. The high flux will enable many investigations to be pursued that are out of range today, by allowing faster measurements, measurements of smaller samples, the increased use of polarised neutrons and detection of weaker signals. The bright neutron beams will be delivered in a unique time structure, with long neutron pulses at low frequency. This structure enables the efficient use of long-wavelength neutrons. Novel neutron technologies will exploit this structure to allow ESS instruments to achieve a wider dynamic range, bi-spectral beams, and tunable resolution as needed, all of which will significantly expand scientific possibilities. State of the art methods for data management and analysis will further enhance capacity and capability.

2.3 ESS technical scope

The main components of the ESS facility are the accelerator, the target station, the instrument suite and the associated buildings and infrastructure.

In the accelerator, protons are accelerated to an appropriate energy for efficiently driving a spallation reaction. The ESS accelerator is designed for high power and high reliability and uses mainly superconducting cavities.

The target station will convert the proton beam from the accelerator, through a spallation reaction, into a number of intense beams of slow neutrons. The technology chosen for the target is that of a rotating wheel. A moderator-reflector assembly surrounding the target transforms the fast neutrons produced in the spallation reaction into slow neutrons. These slow neutrons are guided to the instruments.

In the instruments, the neutrons will be used for probing the properties of materials in a wide sense. The Data Management and Software Center in Copenhagen (DMSC) provide support and services for the management and scientific analysis of the data.

In addition to these parts there is an infrastructure of services, supporting laboratories and workshops, offices and amenities for staff and users. Figure 1 presents a preliminary layout of the site north east of the city of Lund, Sweden.

Description

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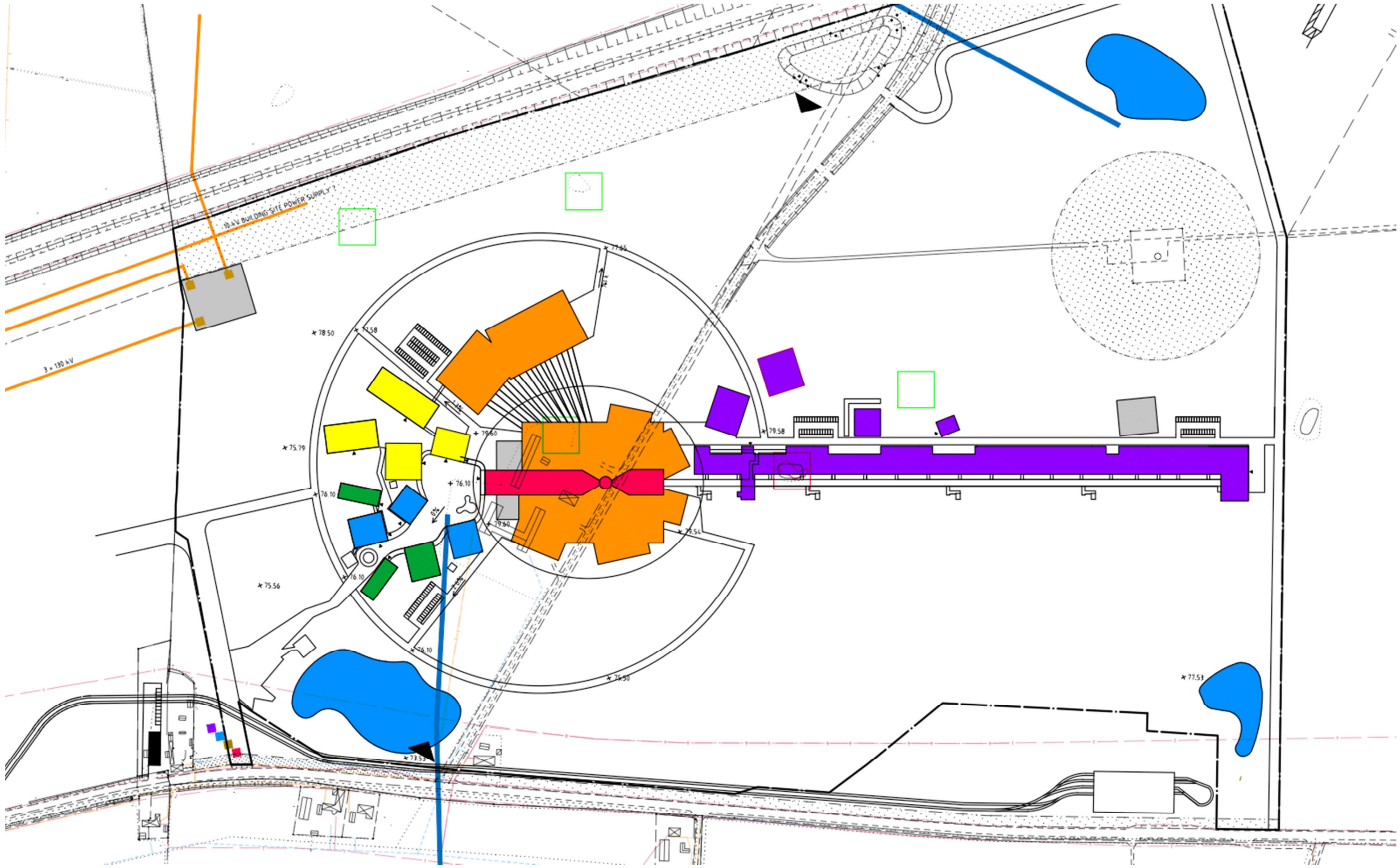

Figure 1: Preliminary facility layout.

2.4 Project schedule

The

Figure 1 shows the master schedule of the ESS construction up to the delivery of a fully operational facility [3]. This schedule encompasses the major milestones for the pre-construction, construction and operation phase, the first neutrons to instruments and the expected full beam power on target.

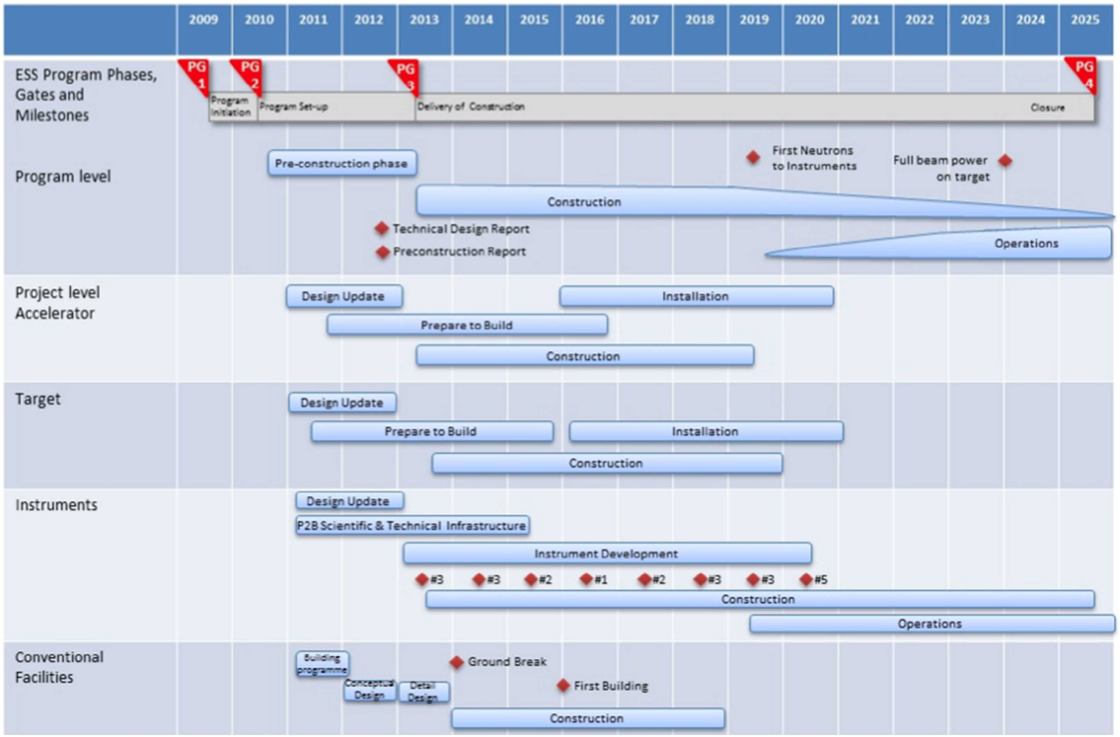

Figure 1: ESS Master Programme schedule.

2.5 Breakdown Structures

The Work Breakdown Structure – WBS – is a hierarchical tree-like depiction of the development activities as they relate to:

- The ESS system architecture,
- The ESS life cycle,
- The ESS specific collaborative scheme, especially the in-kind contributions,
- The present "green field" status of ESS AB.

During the construction phase, a significant proportion of the technical activities will be performed by teams whose members are from several geographically diverse organizations. Funding and control of these remote tasks and activities is one of the major challenges of the ESS construction phase. For each phase, the WBS will be broken down and maintained by the programme team.

The Product Breakdown Structure – PBS – is a hierarchical tree-like decomposition of the facility into its constituting elements. The PBS reflects the architecture of the ESS system. Typed trace-links will establish the relationships between the PBS elements and other structure items and documents. In this respect, the PBS will be an entity aggregating several types of information related to a system (see Figure 2).

A PBS element is the product of an activity of the construction phase. A PBS node can represent either a software item or a hardware item. A "leaf" of the PBS is named *component*. This entity will be the connection point for generating a Bill of Materials, itself connected to a CAD structure if applicable. The BoM associated to a component may be an instance of a centralised classification or ESS catalogue. This mechanism will support standardisation and reduce the engineering effort by reutilizing already engineered BoM. Any of the elements depicted in the figure below may be trace-linked to a document.

It will be possible to trace-link a PBS node to a Location Breakdown Structure node for specifying the location of a system. The history of the relationships shall be maintained by the PLM system for e.g. supporting future decommissioning activities. Indeed, it shall be possible at any point in time of the ESS life cycle to determine when and where equipment was used. This also means that the Location Breakdown Structure will contain information related to zoning.

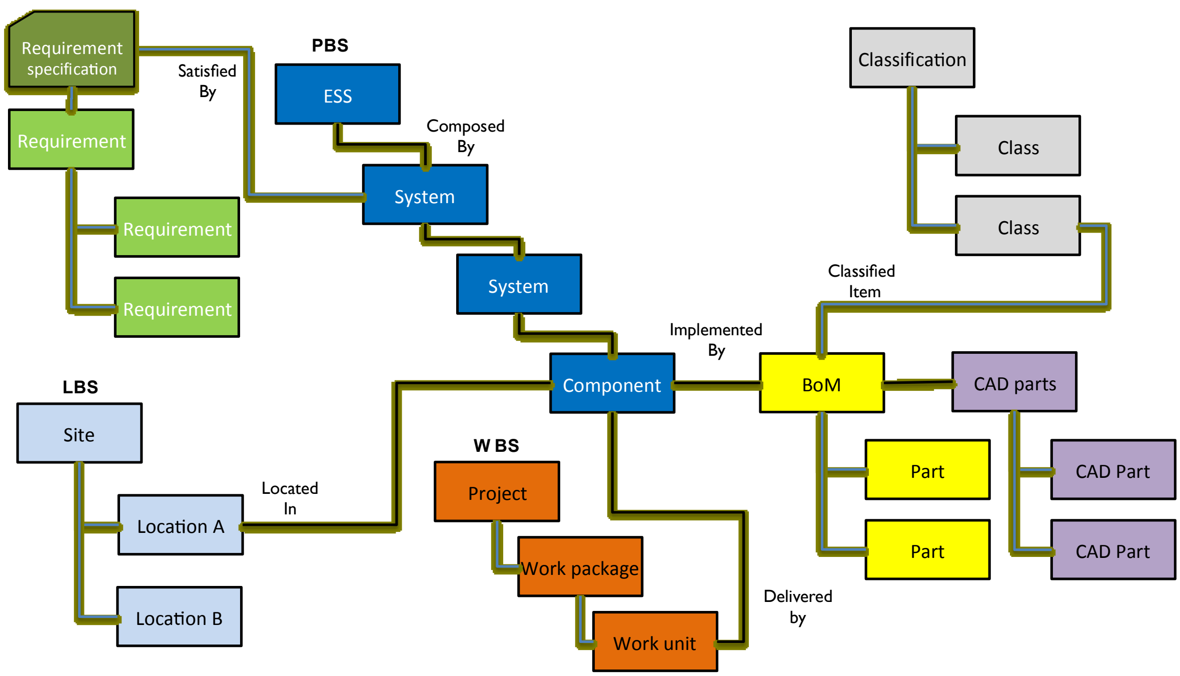

Figure 2: Breakdown structures.

3. SYSTEMS ENGINEERING PROCESS

3.1 ESS Life cycle

Related standards: ISO15288:2008 Clause 6.2.1

The Figure 3 shows the ESS programme life cycle master phases. It applies to any ESS system.

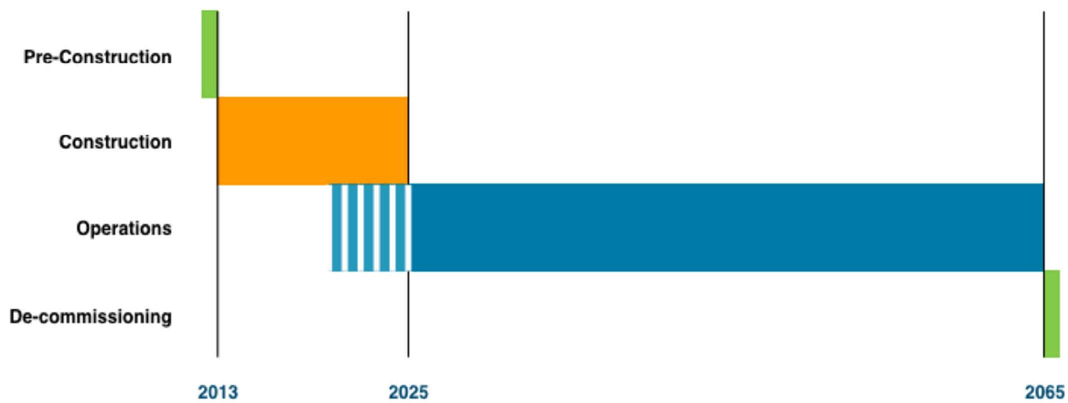

Figure 3: ESS life cycle phases.

3.1.1 The preconstruction phase

This phase focuses on the baselining process for the ESS facility. Starting from the 2003 baseline, this Design Update – DU - subproject will provide a preliminary design prior to the construction phase. The main deliverables of the pre-construction phase are described in reference [3].

The deliverables of the preconstruction phase will make use of the experience of the contributing partners worldwide and lessons learnt in existing facilities such as SNS, PSI or Isis. During this phase, a contingency budget will be defined to cover commodity price fluctuations and the possible extra cost induced by the necessary adaptation of the state-of-art hardware to the particular needs of ESS. The consolidation of these adaptations will be carried out through engineering modelling early during the construction phase. In this context, the ESS design will implement COTS and state-of-art components as much as possible.

3.1.2 The construction phase

The construction phase encompasses the activities which will transform and integrate each pre-design of the preconstruction phase into products ready for the ESS operation. The construction phase will end in 2025 after completion of the 22 instruments suite.

3.1.3 The operation phase

The operation phase of ESS will occur over time starting with the operation of major accelerator and target systems as well as the first instruments in 2019 and continuing with the final commissioning and handover into full operations with 22 neutron instruments in place 2025. The expected duration of the operation of the ESS with its nominal or possibly upgraded performances is 40 years.

3.1.4 The decommissioning phase

After its utilization period, the facility will be decommissioned during a period of 7 years for restoring a green field status to the hosting site.

3.2 Design reviews

3.2.1 External design reviews

Monitoring of the development will be performed by external reviews [3]. These reviews are described in the following table. These reviews will occur during the whole construction phase.

Field of interest	Concerned systems	Committees
Technical	Accelerator and Control systems	ATAC
	Target and dump systems	TTAC
	Conventional Facilities	CFAC
Scientific and Technical	Instruments suite	STAP, SAC
Safety	Safety related systems	*TBD*
Construction Programme	ESS	Annual review committee

3.2.2 Internal design reviews

<u>Related standards:</u> ISO15288:2008 Clause 6.2.1, ISO10007:2003

3.2.2.1 Technical cycle

The technical baseline will evolve from its functional form to its operational form throughout the SE process. The *Functional Baseline* will depict the functional view (requirements and use cases or concepts of operation) of the ESS. Definition of the *Allocated Baseline* will support the setting up of the architectural aspect (requirements allocation and interfaces). The defined allocated baseline will be transformed gradually into a *Design Baseline* via detailed engineering activities. Design specifications of the design baseline will enable the manufacturing/procurement the ESS products and their associated documentation that will constitute the *Product Baseline*. All verified products and their associated documentation i.e. verification results will establish the *Performance Baseline*. Throughout these technical activities, the ESS team will reduce the scope of possible technical solutions and will increase the resolution of the facility architecture descriptions up to obtaining the *Operational Baseline* (see illustration in Figure 4).

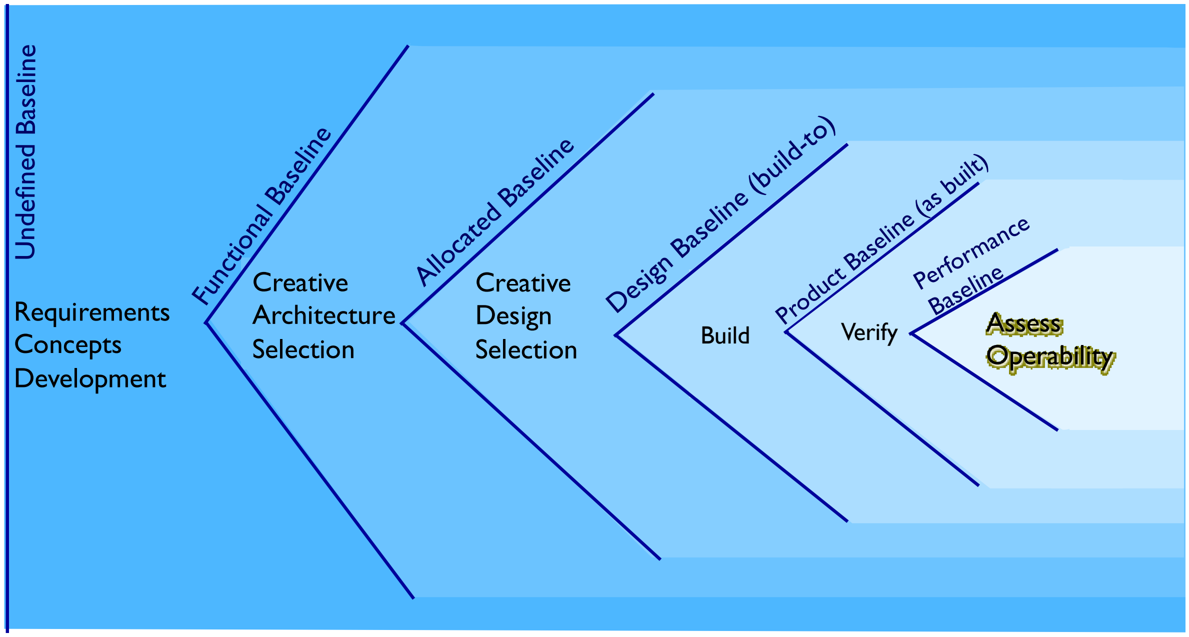

Figure 4: Tollgates for system development maturity.

3.2.2.2 Facility Functional Review

The ESS Facility Functional Review – ESS.FFR – is a formal internal review chaired by the programme director. The CCB of the programme members and the EPG members comprise the review board. The ESS.FFR is held to ensure the objectives and requirements are understood by the affected and associated ESS programme stakeholders.

The Functional Review examines the functional, constraints (including safety and environment) and performance requirements defined for the ESS facility. The review addresses the relevancy of the proposed requirements and use cases.

The Facility Requirement Document (system requirements) and the Concepts of Operations for the ESS facility (stakeholders' requirements and use cases) documents will be draft by the SE office and will be the major inputs for the review.

This review is the first tollgate prior to the release of the requirement for hardware and software design. After passing this first tollgate the requirement tree and the use cases - the functional baseline - will be placed under configuration control [4].

3.2.2.3 Facility Preliminary Design Review

The ESS.PDR examines the proposed facility architecture and the flow down of requirements to ESS systems. It assesses the need for further breakdown of the architecture. It ensures that the technical risk and the safety aspects are addressed.

The facility architecture (internal structure and interfaces, requirements breakdown and allocation to systems) will be specified in the Facility Architecture Specification. This document will identify the need for Interface Control Documents between the ESS systems.

The CCB members comprise the review board of the PDR. The PDR will be the first internal review of the architecture and in this respect, once complete, it will define the PBS at level 1 and 2. This review will initiate the allocated baseline and ensures that all requirements are allocated to ESS systems.

3.2.2.4 Facility Test Readiness Review

The facility ESS.TRR ensures that the facility, its test equipment, support personnel, and test procedures are ready for the verification of the facility. This review examines the produced documentations by the acceptance reviews for the ESS systems (see below) and the verification plan for ESS.

The TRR presided by the chairman of the CCB of the programme will in principle precede the last verification activities of the construction that will complete the performance baseline.

3.2.2.5 Facility Acceptance Review

The ESS.SAR examines the facility, its end products and documentation, and inspection, demonstration, test data and analyses that support its verification. The ESS Acceptance Review ensures that the all system requirements have been satisfied and that the validation activities can start.

The ESS.SAR presided by the chairman of the CCB of the programme will complete the performance baseline by approving the ESS verification results (ESS verification report).

3.2.2.6 Facility Operational Readiness Review

The ESS.ORR examines the actual facility characteristics (e.g. spare parts availability), results of the validation activities and ensures that the ESS AB personnel and procedures have reached the required maturity.

The ORR chaired by the ESS CEO will establish the operational baseline that will be the ultimate set of work products of the technical baseline.

3.2.2.7 System formal reviews

All ESS systems will rely on the same review process than the facility. Refinement of the requirements and concepts of operation for a particular system will be assessed by a *system Functional Review* to be performed at the level 2, then at level 3, etc. Further breakdown of the PBS will be granted by a *Preliminary Design Review*. Throughout this approach, new "leaves" of the PBS tree-like structure will be identified. Each of these items or components will permit the generation of an associated Bill of Materials (see section **Error! Reference source not found.** and 3.2.2.8). Reuse of the already engineered system from the classification will be possible by connecting an instance of a class to a PBS component and will support standardisation. A component will only be the subject of a CDR (see section hereafter), a TRR and a SAR. The requirement document for a component will be first derived from its allocated requirements during the PDR of the upper level system. The requirement specification is amended if needed during the detailed design activity.

Prior to any verification activity, similarly to ESS, a *system test readiness review* will assess the maturity of the resources for supporting the verification activities for a system (test stand accessibility, test equipment readiness, availability of the personnel).
Once the verification activities are performed, a *system acceptance review* prior to integration will be held. The system is then delivered to the team responsible for the upper level.

3.2.2.8 *From system to component formal reviews*

The system life cycle will include a detailed engineering phase (design and build or procure). When homemade design is performed, a Critical Design Review concludes the design activity. The CDR assesses if the design meets all system requirements with acceptable risk and within the cost and schedule constraints.

The CDR demonstrates that the maturity of the design is appropriate to support proceeding with full-scale fabrication, assembly, integration, test, and future operation and decommissioning.

Design activities between the PDR and the CDR for a system of interest will comply with the design process as defined in the reference [5].

3.2.2.9 *Deliverables for reviews*

Review	Deliverables	Level of interest
FR	• System Requirement Document • Concepts of Operation	System
PDR	• System Architecture Specification • Interface Control Documents • System Verification Plan	System
CDR	• System Requirement Document • System Design Description and related documents (drawings, P&ID, etc) • Interface Control Documents • System Integration Plan • System Operation and Maintenance Manual • System Verification Plan	Component
TRR	• System Verification Plan	Component and system
SAR	• System Verification Report • Verified products • System Integration Plan	Component and system
ORR	• ESS Validation Report • Validated products	ESS

3.2.2.10 *Incremental development and delivery*

From 2019, the operation will start while the construction activities will continue and will be completed by the end of 2025. In this respect, increments will be developed and delivered that allow for assembly into an operational system with limited functionality with later increments that add increased functionality.

The Figure 5 illustrates this feature: successive deliveries will upgrade the facility in operation (e.g. from 1 to 22 instruments).

The Figure 6 shows the schedule of the design reviews at the ESS level.

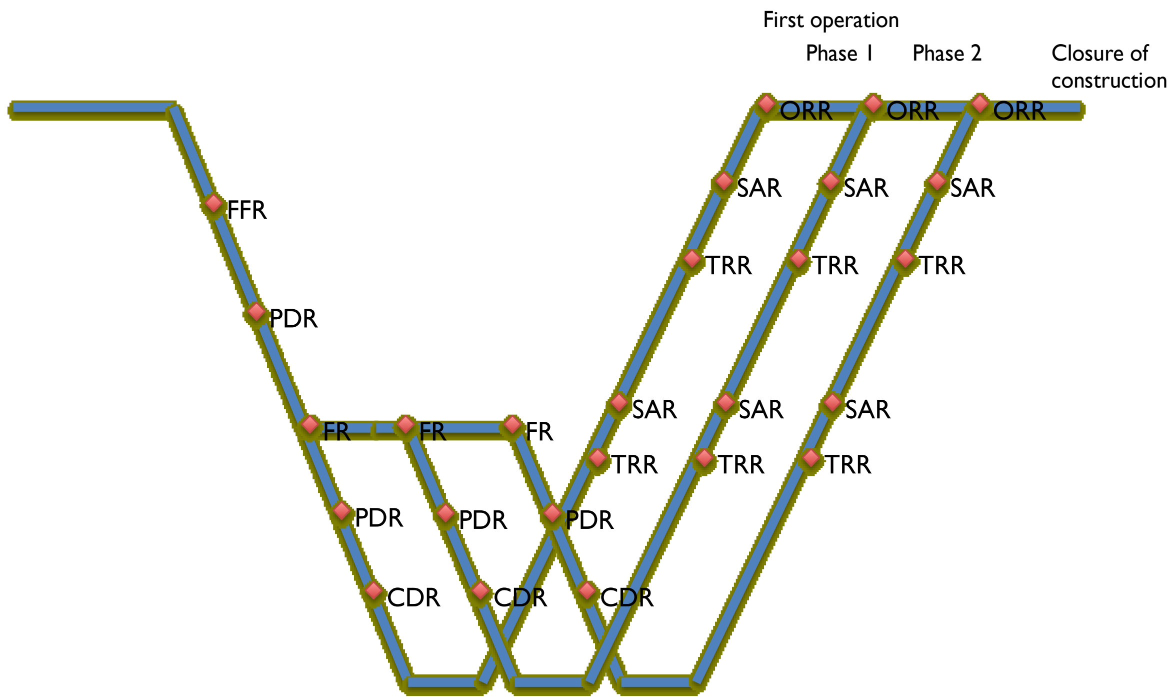

Figure 5: The incremental development and delivery cycle for ESS construction.

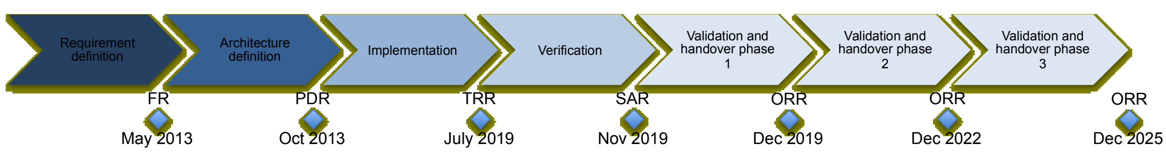

Figure 6: ESS design reviews master schedule.

3.3 Key Systems Engineering activities

Key Systems Engineering activities will be developed throughout the pre-construction and construction phases up to and including the validation phase. The major SE activities include:

- Environment identification (stakeholder, interacting entities),
- Requirement identification and management,
- Operational concepts or use cases definition,
- Architectural design (interfaces),
- Integrate Reliability, Availability, Maintainability and Safety in the design process,
- Assess technical risk for dimensioning performance contingencies.

All these activities are iteratively performed at different levels. Each activity contributes to the refinement of the others. The verification activity is initiated just after the requirement definition activity to:

1. Ensure adequacy of the verification and the requirement set,
2. Identify the design constraints induced by verification activity.

During the construction phase the technical activities shall be monitored to ensure that trace links between requirements and verification activities are maintained as well as ensuring the efficient management of non-conformities and change requests. In this respect, the SE process is an essential part of the configuration management process [6].

The description of the SE process for ESS will be hereafter based on textual and light processes specifications. Indeed, the figures describing the processes will not show the flows of products and the roles associated to each activity. A detailed process map is depicted in Appendix A.

3.3.1 Context identification

Related standards: ISO42010:2009, ISO15288:2008 Clause 6.4.1

3.3.1.1 Stakeholders

Requirement elicitation shall be first based on the analysis of the system stakeholders. Indeed, stakeholders' knowledge is means for identifying the various viewpoints from which the views constitute the ESS architecture descriptions (see Figure 7). In this respect, ESS stakeholders will be identified and classified throughout SE model like the "onion" model.

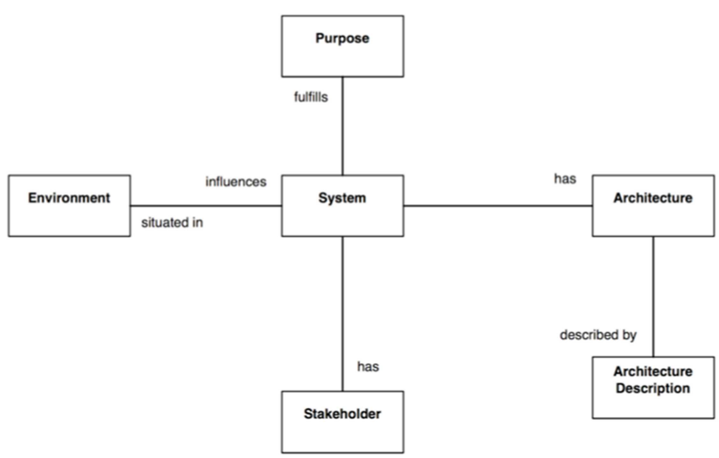

Figure 7: Conceptual model for architecture descriptions.

3.3.1.2 Interacting entities

Identification of the ESS interfaces will be defined via workshops with the ESS developers. Context diagrams will be established and converted into an ESS context diagram. The workshops will determine the interacting entities and their relationship with the ESS system (client/supplier or other perspective).

3.3.2 Requirements

Related standards: ISO15288:2008 Clause 6.4.1 and 6.4.2

3.3.2.1 Requirement identification

The ESS requirements will be organized into two tree-like hierarchies. Figure 8 shows how the requirement trees are related. The first tree will contain the stakeholder's requirements defined from the ESS statutes and other sources like collaboration agreements. From this first tree, the ESS system requirement tree will be derived. This second tree will provide the mechanism for specifying what is necessary down to the lowest level of the system for each state of the life cycle. System requirements are also defined by integrating the context view related to the interacting entities. Each requirement is traced to its source and contained specific attributes.

The ESS system requirements will be organized in three categories. First category is *functional requirements* that is the "what" is performed by the system. The second category is *constraint requirements* that is the "How" a function is performed. Both functions and constraints can be associated to a set of *performance requirements*, which constitutes the third category, the "How well". This last category:

- Either quantifies the satisfaction level of a functional or a constraint requirement, e.g., temperature between 300 and 350 K,
- Or qualifies the satisfaction conditions of a requirement (e.g.: compliance with a standard).

The kinship between functions, constraints and performances is mandatory to properly build the requirements tree and provide the necessary trace links for change request management. During the requirements definition activity, working groups will take care that the following principles are respected:

- each requirement is necessary,
- each requirement is unique,
- each requirement is verifiable, (NB avoid "optimize", "maximize" or "minimize" which are unverifiable statements in many cases),
- ensure that each phase of the life cycle is addressed,
- for performance requirements, state the units and the tolerance (x±y *unit*).

The requirements can be further labelled for enhancing sorting with additional categories:

- Interface,
- Safety,
- Radiation safety,
- Conventional safety,
- Electrical,
- Environment,
- Regulatory,
- Operational,
- Maintenance,
- Testability,
- Supportability,
- Usability,
- Instrumentation and Control,
- Structural,
- Security.

Some requirements flow between elements or are common amongst all elements:

- Electrical systems requirements,
- Electromagnetic Interference/Electromagnetic Compatibility (EMI/EMC) Plan,
- Environment, Safety and Health objectives, and
- Standards and norms.

These requirements might be documented in dedicated documents as reference - ESS standards - to be called in the requirement tree.

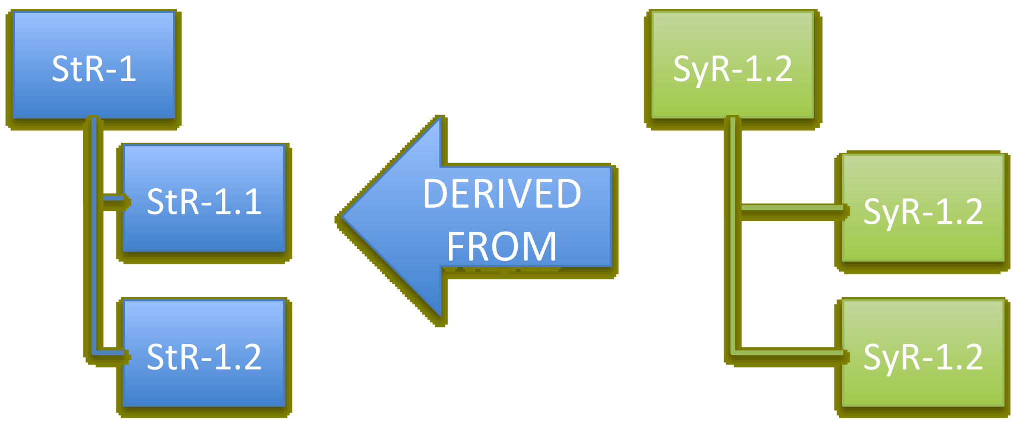

Figure 8: ESS requirements trees relationship.

3.3.2.2 Requirements Management

One common database for tracking ESS requirements (ESS requirements tree) will be set up and maintained. This database will be part of the ESS platform CHESS, which will host the ESS meta-model. It shall be ensured when requirements are recorded into this common database that each item has the followed attributes filled-in:

- Responsible,
- Tracelink to other requirements (derived, contained),
- Source and/or Rationale,
- Verification method,
- Technical Risk Id if applicable (the risk being the source),
- Priority,
- Status.

The requirement responsible will be by default the system owner for which the requirement has been allocated to. The "derived" relationship will be the relationship between requirements from two different specifications. All requirements allocated to a system will constitute the requirement specification for this system. The tracelink "contained by" will define the relationship of the requirement within a specification. In this respect, "contained by" relationship may used as a "refined by" relationship.

The source attribute is a reference to a document stored in the document management system. The document is preferably the result of an analysis (functional, risk, trade-off, maintenance task, fault tree, failure mode effect).

All pre-existing requirements packages developed so far by different stakeholders will be analysed and possibly reformulated to enable their consistent integration in the ESS requirement tree (see Figure 9).

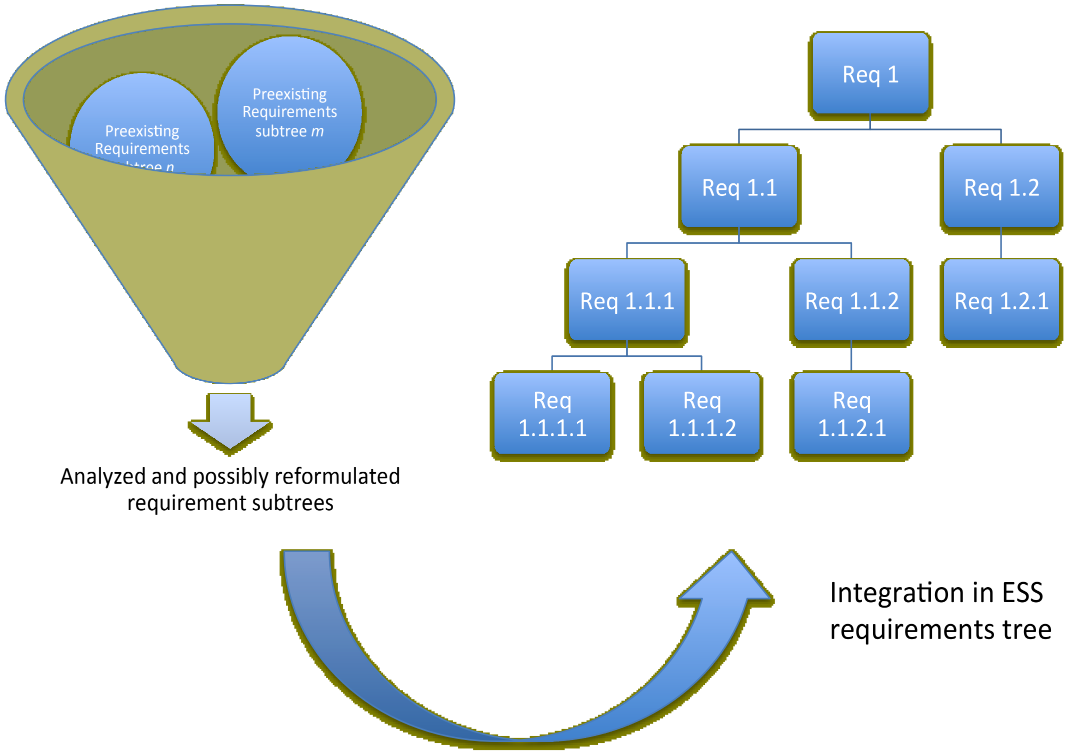

Figure 9: Integration process of pre-existing requirements in the ESS database.

3.3.2.3 Requirement Quality Verification

Programme participants with the support of the SET will make sure that each system requirement satisfies criteria in section 3.3.2.1, the required trace links exist and are valid, each requirement is verifiable and the verification activity is valid, the attributes of the requirement are complete and consistent. The SET will perform quality audits for reporting to the CCB and EPG the current status of the requirement definition activity.

3.3.2.4 Requirement products

Facility level

The ESS facility requirements document –FRD- serves as the top-level for the requirements flow-down. It encompasses the scientific requirements and facility constraints. Once uploaded in CHESS by the SED, the FRD will be issued to EPG one couple of weeks before the facility functional review. The FRD is a level 1 document. The SEM will orchestrate the activities that will address the FRD. The FRD will be placed under configuration management after sign off and release [6].

The FRD will address the safety and environment related requirements for the facility to ensure that the ESS facility has in place effective, practical and achievable means to provide for the health and safety, protection and welfare, of employees, visitors, contractors and the environment. The safety requirements will be elaborated via the safety assessment process [9] integrated in the ESS technical processes as defined hereafter.

ESS system and lower level systems

One requirement document for each of the ESS systems will be established. The working groups eliciting requirements will make sure that the requirements developed in these documents are validly linked to the requirements developed for the upper level system. This breakdown of the requirements will have to be repeated at lower level as decided at the preliminary design review for the system/subsystem of interest.

The *system requirement document* is derived from its allocated requirements during the PDR at the upper level. This approach is continued at lower level. These documents will be placed under configuration control after sign off and release.

3.3.3 Operational concept development

Related standards: ISO15288:2008 Clause 6.4.3

3.3.3.1 Definition process

The Operational Concept or Conopts definition begins in parallel of requirement definition phase and a Conopts baseline is established by modelling use cases for the facility. Each identified stakeholder will be considered by assessing the generic use case: a stakeholder wants to "do something" with the facility. The "do something" being the use case to be modelled in detail. The Operational Concept defines and addresses the following topics:

- Operational modes,
- Maintenance:
  - level of repair, repair policy,
  - types (disposal, corrective, preventive, inspection, on site, off site)
  - recurrence and duration,
- Data flow diagrams,
- Data archiving concepts.

Each use case is modelled *either* with a sequence specification e.g. sequence diagram when there is a need for modelling an interaction between the stakeholder, the system and possibly other interacting systems *or* with activity specifications e.g. activity diagrams for defining the set of activities performed by the system for the utilisation of interest. As depicted in Figure 10, activities specification must contain the control flows of the activities (performed in parallel or in series, triggering events) and the object flows between the activities (flows of matter, energy, information, etc). A set of activities might be grouped into a master activity used for representing an operational mode. Modes are called in system states as needed. In this respect, the system will exist in one state at a time and will execute modes relevant for that state.

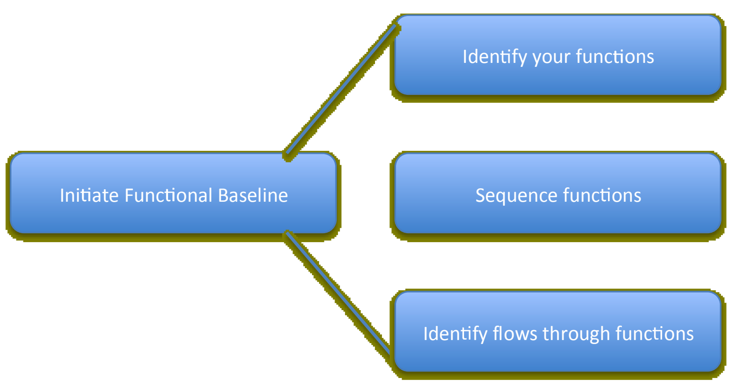

Figure 10: Process for developing a functional decomposition.

Throughout the Conopts development the different activities/functions of the system will be defined respecting the rule 5±2 different activities/functions per level of abstraction.

The Operational Concepts are refined and updated throughout the SE process at lower levels. Activities/functions are broken down for the system to which they have been allocated as needed. Allocation of function as such will play a major role for supporting safety design and availability analysis where e.g. failure rate will be allocated to functions and then to systems. In this respect, the functions must be as independent as possible.

3.3.3.2 Operations Concepts Products and reviews

The Conopts are specified in the *System Concepts of Operation* documents. This document is a deliverable for the system functional review. At component levels, the System Concepts of Operation documents are used for elaborating the *System Operation and Maintenance Manuals* at a later stage.

3.3.4 Architectural design

Related standards: ISO15288:2008 Clause 6.4.3

3.3.4.1 Hierarchy

The following hierarchy will be used during the construction when defining the logical decomposition of the ESS facility into constituting elements.

3.3.4.2 Architectural design via functional and constraint requirements

The ESS system is broken into elements, which will perform specific functions while satisfying a set of predefined constraints. Each element is itself decomposed into elements as needed. The decomposition strategy is based on the following principles:

- Reduce the number of interfaces between the constituting elements,
- Specialize the elements,
- Separate service-functions[1] and ESS specific functions.

Service-functions encompass data, control, structural, utilities and physical access functions. The element specialization is a cost, schedule and management complexity-reducing factor (see Figure 11).

PBS levels	System of interest
Level 1	ESS facility
Level 2	ESS systems (accelerator, target, etc)
Level 3	Subsystems
Level *n*	*(n)*-subsystems of a *(n-1)*-subsystem

[1] Service functions are also called cross-functional services or enabling functions as they support several systems with the same nature of service.

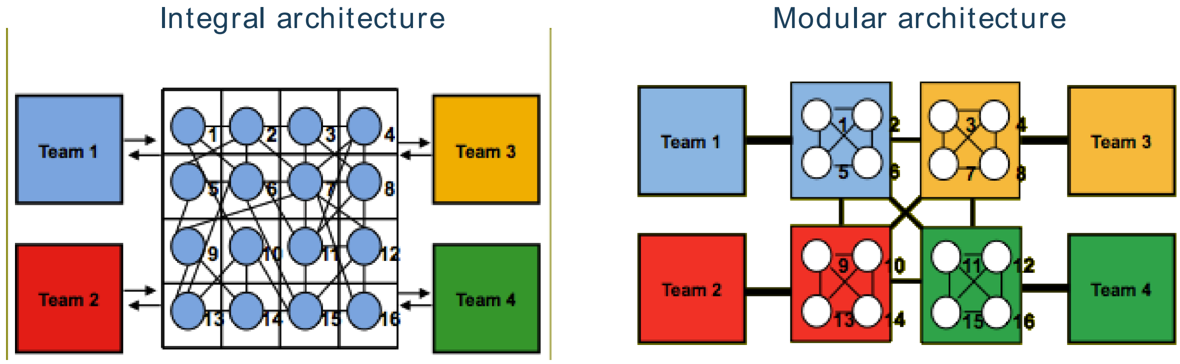

Figure 11: Illustration of the advantages of a modular architecture.

Interfaces between the elements will be addressed and type of flows through the interfaces will have to be identified like the:

- Control flows,
- Utilities flows for electrical flows, fluid flows
- Data flows,
- Structural flow for mechanical interfaces,
- Opening flow for physical aperture, entrance and exit.

At this stage, elicitation of the architecture mainly consists in breaking down requirements via functional analysis workshops (see 3.3.3.1) and grouping these requirements by allocating them to dedicated systems. Selection of one alternative could be supported by either Quality Function Development technic or by applying the Analytic Hierarchy Process as depicted in section 3.3.4.5.

From the context identified in section 3.3.1.2, the facility interfaces are defined and propagated internally to its systems. This specification can be performed with an internal block diagram (see Figure 12).

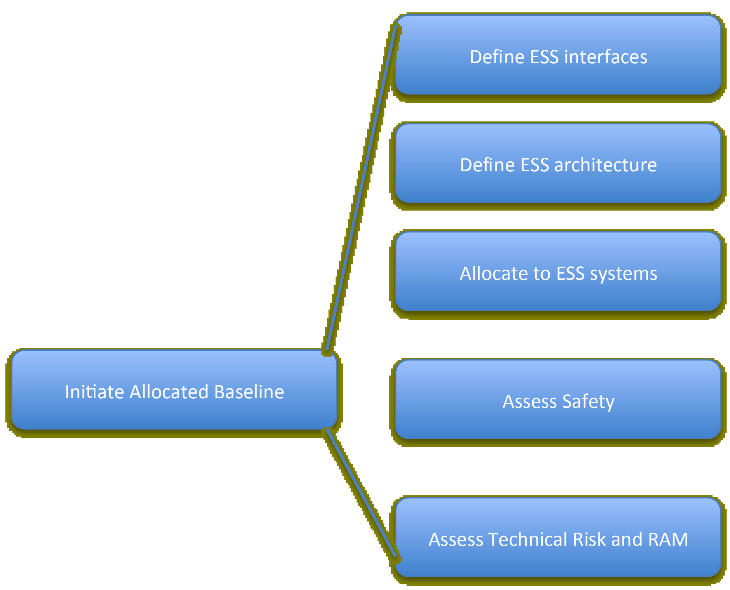

Figure 12: Allocated baseline definition process.

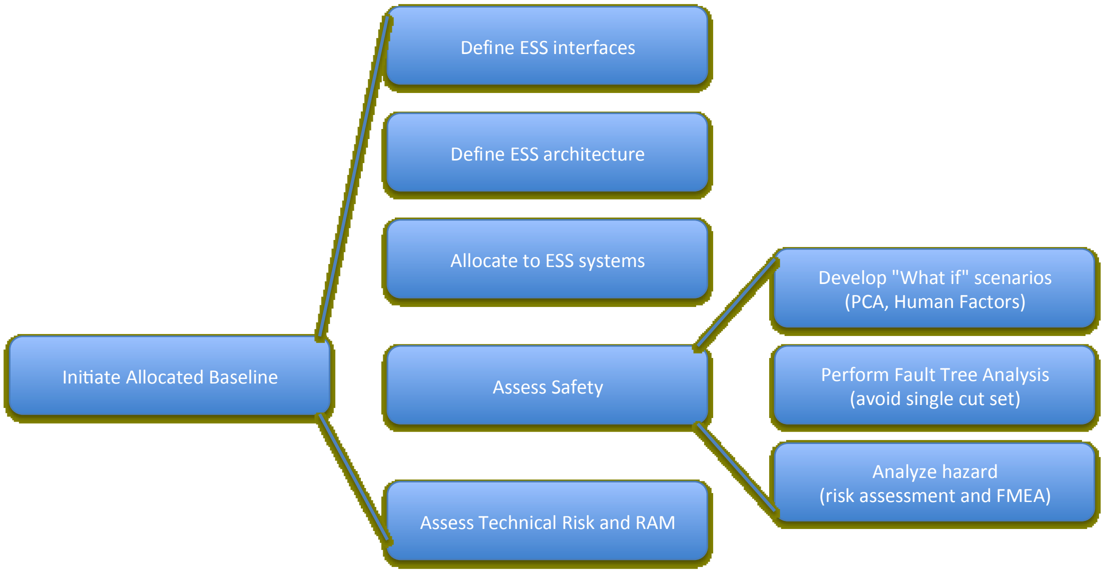

Figure 13: Safety assessment process as integrated in the definition of the allocated baseline.

Integrating safety

Related standards: ISO61508:2010 Part 1, ISO15288:2008 Clause 6.4

The safety of a system is assessed throughout various approaches. Use cases or conopts might be revisited to develop "what if" scenarios focusing on the human factors (see Figure 13). Changes of the previously approved concepts of operation will be submitted to the relevant CCB or will be part of the preliminary design review. Hazards induced by the functions and the architecture identified so far will be assessed via Failure Modes and their Effect Analyses and/or risk analyses workshops for discovering safety requirements. Critical failure modes are subject to studies via fault trees analyses to identify single cut set and then the necessary changes of the system specifications (architecture and/or requirements).

3.3.4.3 Integrating Reliability Availability and Maintenance and technical risk

Related standards: ISO60706-1:2006

The RAM requirement for ESS will be elaborated in a top-down approach. RAM performance requirement, e.g. failure rate, mean time to repair and lifetime will be apportioned by integrating equally the importance and the complexity of the allocated functions to the system of interest. Workshops will rank the allocated functions for each system by comparing them by pair in term of relative importance and complexity. This relative comparison will allow weighting factors calculation for sharing the RAM performance budget. This step of the development is part of the allocation process when functional requirements have been considered (see 3.3.4.2).

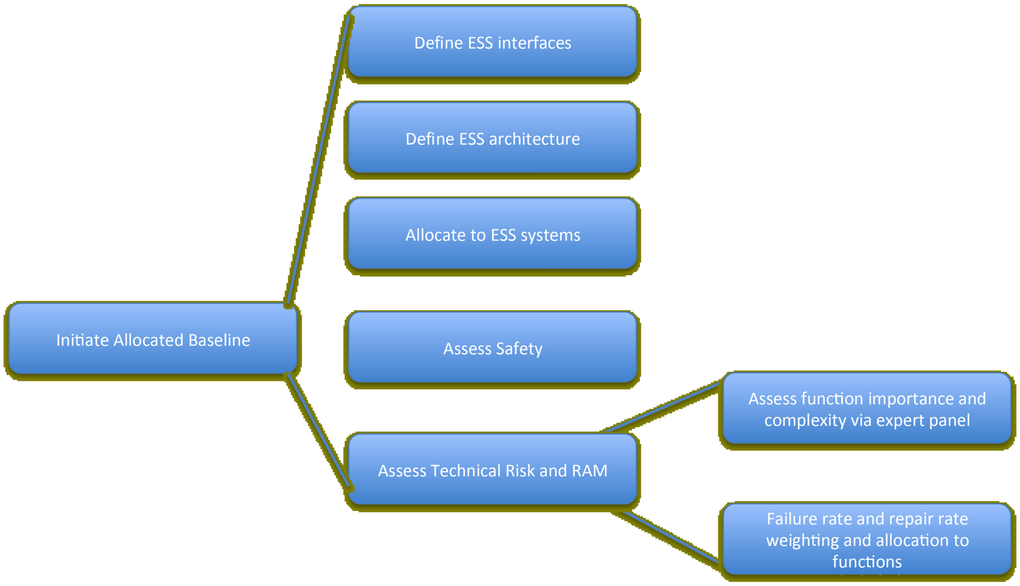

Figure 14: RAM performance requirement allocation process.

At all levels of the ESS decomposition and ideally once at least functional and safety aspects have been analysed, allocation of performance requirement must be considered by integrating the technical risk for defining the performance contingencies. For the system of interest, workshops will identify major risks that might impact the performance satisfaction. Mitigation actions might consist in defining new requirements, changes of the proposed architecture at that stage or any other actions. Elicitation of the technical risk will rely on the risk management process [10].

Satisfying performance requirements e.g. RAM requirements with a particular architecture and a set of use cases have to be assessed throughout various analyses. Use cases might be analysed considering "what if" scenarios, Perception Cognition Action analyses for assessing human factors. Critical failure modes identified with FMECA and the current architecture will be inputs for Fault Tree Analyses in which single (or more) cut set(s) will be avoided by changes in the architecture or elicitation of new constraint requirements like a preventive maintenance requirements (see Figure 15). In this respect, RAM analyses will use the same approach than safety analyses. The achieved RAM performances with the proposed changes will be compared with the RAM performance requirements for assessing the effectiveness of the change. FMECA might use Ishikawa "cause-and-effect" diagrams for identifying failure modes (see Figure 16). By performing FMECA, the following goals will be achieved: hazard elimination, mission capability, diagnostics development identification, support operational planning.

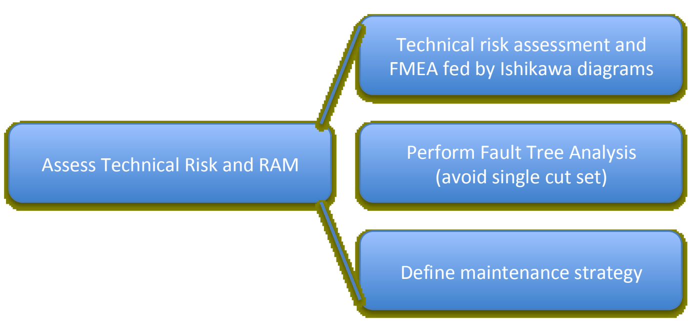

Figure 15: Process for technical risk and RAM assessment.

Each allocated system might be doubled if needed in the architecture considering assumed achievable performance for one unit. For supporting this particular aspect of the analysis, a RAM database will be established and be populated with standardized values from references like [1] and data from existing similar facilities. It shall contain, for each system, performances achieved so far for:

- Failure rate,
- Life time,
- Operational conditions (personnel and environment),
- Mean time to repair,
- Source.

The management of this database will have to include a feedback loop connected to operation and testing failure reports. This step of the process will be covered in a future revision of this document to establish how Failure Reporting, Analysis, and Corrective Action System –FRACAS- will be addressed at ESS.

By considering the operating periods, maintenance periods and budget defined in the concepts of operation document, lifetimes, repair times and reliability will be assessed for defining the maintenance strategy to be developed in the *System Operation and Maintenance Manual* (see 3.2.2.8). This activity might result in new requirements for the designers to be traced to either the *concepts of operation document* or the *System Operation and Maintenance Manual*.

The definition of the preventive maintenance will be reliability-centered (see Figure 16 and Figure 17). The emphasis is on the establishment of a cost-effective preventive maintenance programme based on the reliability information derived from the FMECA that is failure modes, effects, frequency, criticality, and compensation through preventive maintenance, and then criticality reassessment (see figure below).

When a Preventive Maintenance – PM - is required, its definition can be established via a Maintenance Task Analysis – MTA - as shown in Figure 18.

Maintenance policies can be decided via a Level of Repair Analysis, the levels of repairs being derived from the ESS concept of operation document. The maintenance activities for each level of repair are defined with a MTA (see Figure 19). When corrective maintenance is preferred for e.g. economical reasons, the same process applies for defining the corrective maintenance policy and activities.

PM and CM tasks for COTS product and subcontracted products shall be part of the documentation delivered with the product. This documentation will be referenced in the *system operation and maintenance manual* related to the SoI.

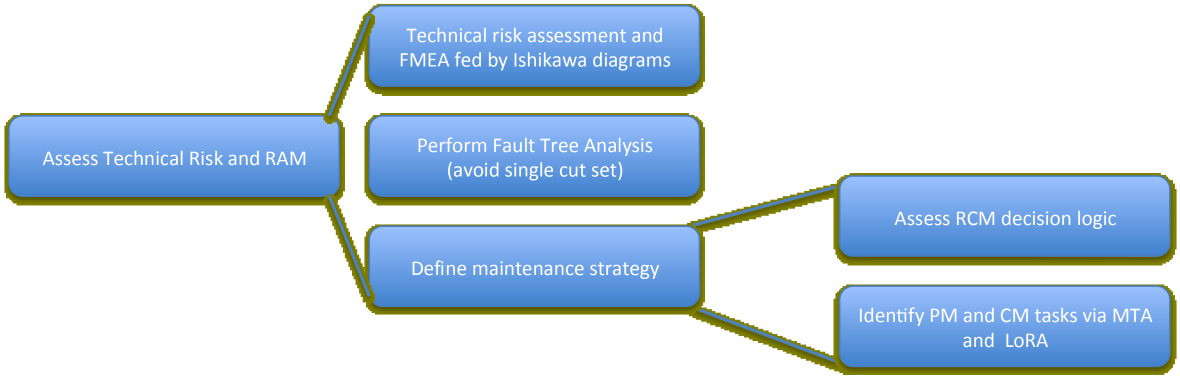

Figure 16: Maintenance Analysis Process.

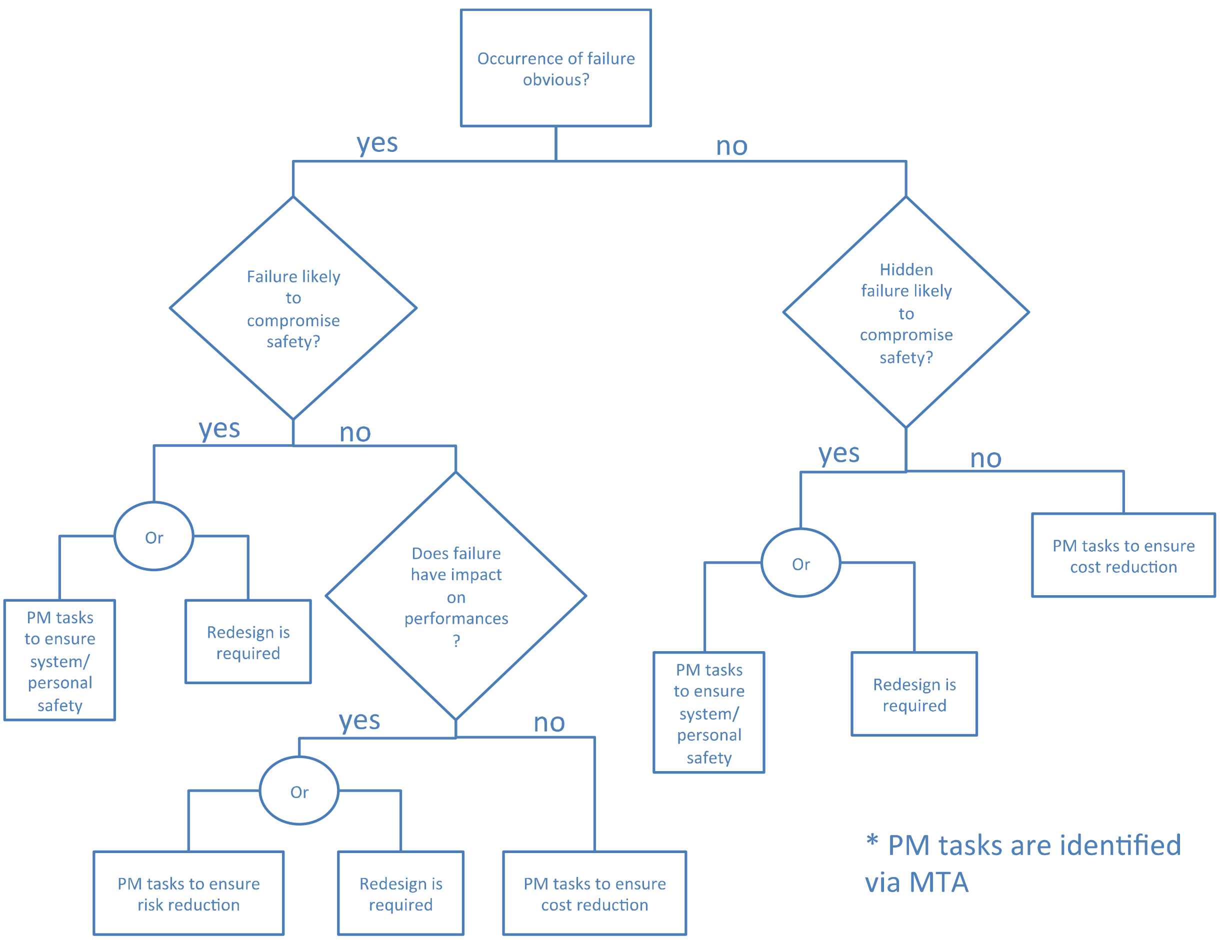

Figure 17: RCM decision logic for PM task need assessment.

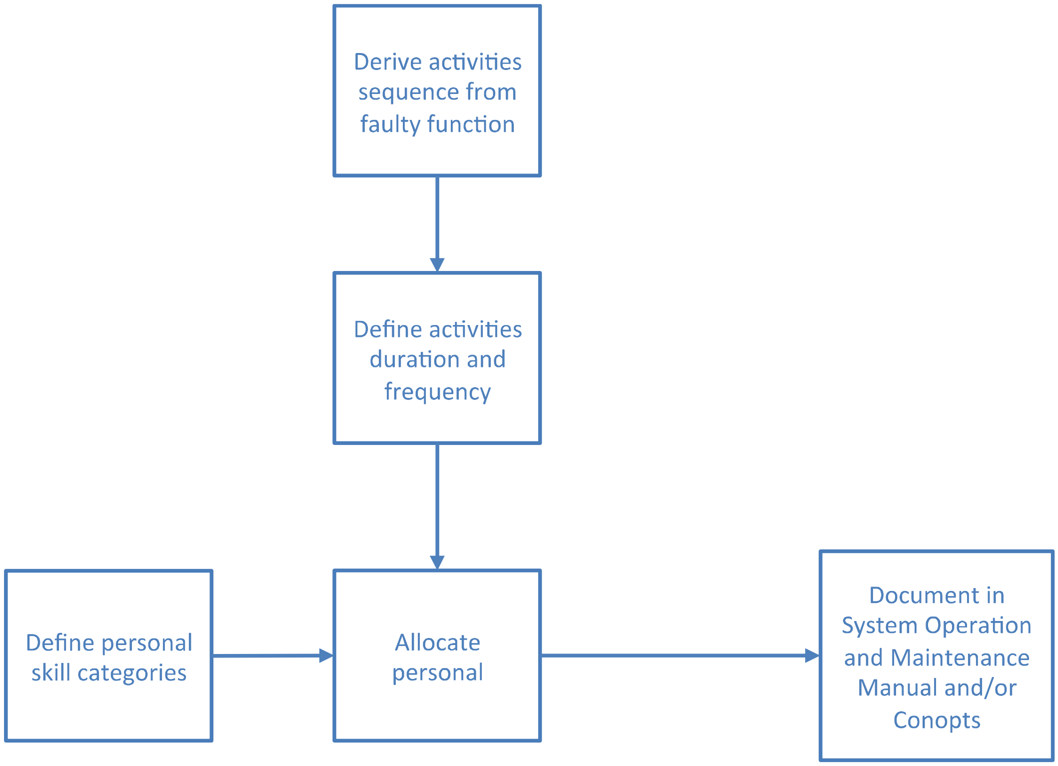

Figure 18: Maintenance activities definition via Maintenance Task Analysis

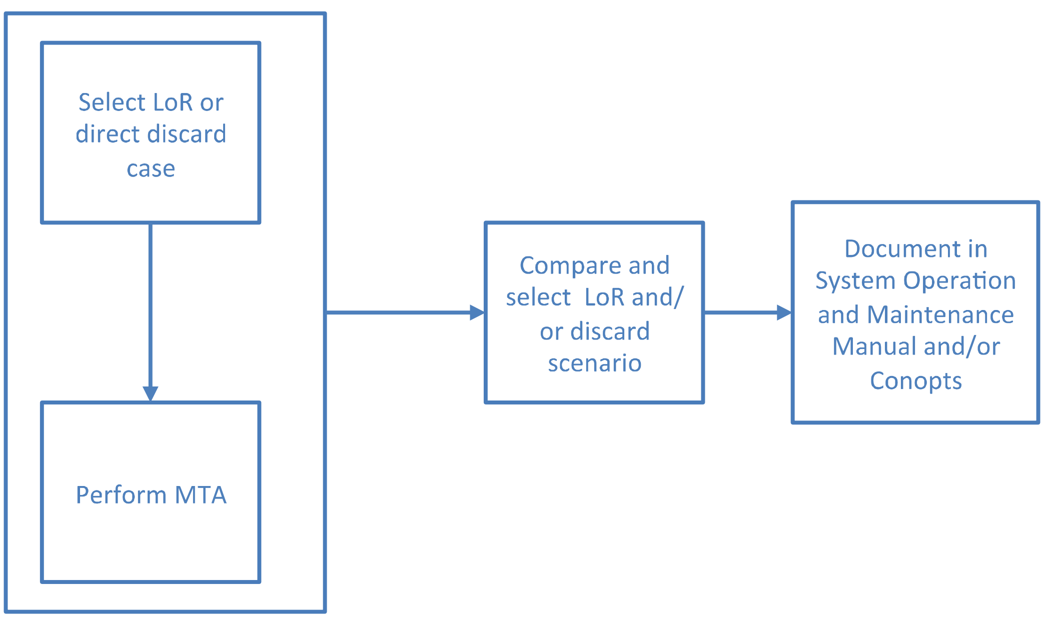

Figure 19: Maintenance policies definition via MTA and Level of Repair Analysis

3.3.4.4 Architecture and design products

An early product of the architecture definition will be the identification of logical blocks and their internal block diagrams that will build up the Product Breakdown Structure of the ESS model. It must be ensured that a block with valid attributes describes each system. An Internal block diagram describes the further decomposition of the system into subsystems. These diagrams are integrated in a *System Architecture Specification*. When approved changes occur, the block diagrams shall be updated according to the considered levels to reflect decisions made within the scope of the configuration management process. The block diagrams within the meta-model are not placed under Configuration Control but will be communicated on the ESS project website for information (http://194.47.240.63:8080/cameoework/signin.jsp). The *System Architecture Specification* documents and the *Interface Control Documents* are together the architecture specifications. These documents are under configuration control one sign off and release.

3.3.4.5 Trade-off studies, alternative comparisons and off-core activities

During the acquisition process, various alternatives will be identified as candidates for satisfying a set of requirements. There are many methods for scoring the solutions against each value measure. This SEMP considers five categories: operations, testing, modelling, simulation, and expert opinion. Whatever the selected method, it is crucial that the candidate solutions are assessed against their capability to satisfy the requirements.

Operational feedback is so far the best source of data for evaluating solutions. However, it is very difficult in practice to obtain operational data for each alternative ensuring that these data are associated to a similar environment. In this respect, in many cases other scoring methods will have to be used.

Testing based on the development of a prototype or engineering model is a scoring method that tends to be very close to the operation. The drawback of this method is obviously the price and delay for performing the test.

Modeling usually refers to the development of mathematical models. Queuing models are important when determining service times for facilities layouts. If this type of problem becomes more complex and especially if there is a stochastic nature of the problem analysts use simulation to help determine die value measure scores.

Simulation is more widely used as computing power increases and simulation packages make the building of these simulation models easier and quicker. The increasing complexity and sophistication of the modern simulation tools tends to render the numerical simulation similar to a virtual prototype for a relative low cost when compared to developmental or operational testing.

Expert opinion is often considered the simplest and quickest means of obtaining the value measure scores for the candidate solutions and potentially the most questionable with its subjective nature compared to objective evaluation means described above. Methods for scoring alternatives with the support of experts are numerous and this plan will mention a few of them for their relevance in the context of the SE process:

- Quality Function Deployment,
- Analytic Hierarchy Process,
- Principal Component analysis,
- Life cycle cost analysis.

The priority of the requirement as defined in section 7.2.1 shall be used to weight each requirement when performing the comparison. Value analysis might consider ratio e.g. either performance score / cost score or performance score / risk score. The latter obviously requires that a risk analysis is performed. It is interesting to note that the risk may be included in the ratio performance score / cost score as a contingency.

3.3.5 Implementation

Related standards: ISO15288:2008 Clause 6.4.4

Considering one system, the implementation phase of the ESS development is the lowest level of the V-cycle where the first branch of the V is a decomposition of the system and the second branch represents its composition (see 3.2.2).

At any level of abstraction, during the PDR, it will decided if the decomposition of the considered system in accordance with the process described from sections 3.3.2 to 3.3.4 must be continued or if the system is a component and then a detailed design phase is required. This respectively corresponds to the activity "Implement subsystems" and the activity "Engineer subsystems" in the Figure 20.

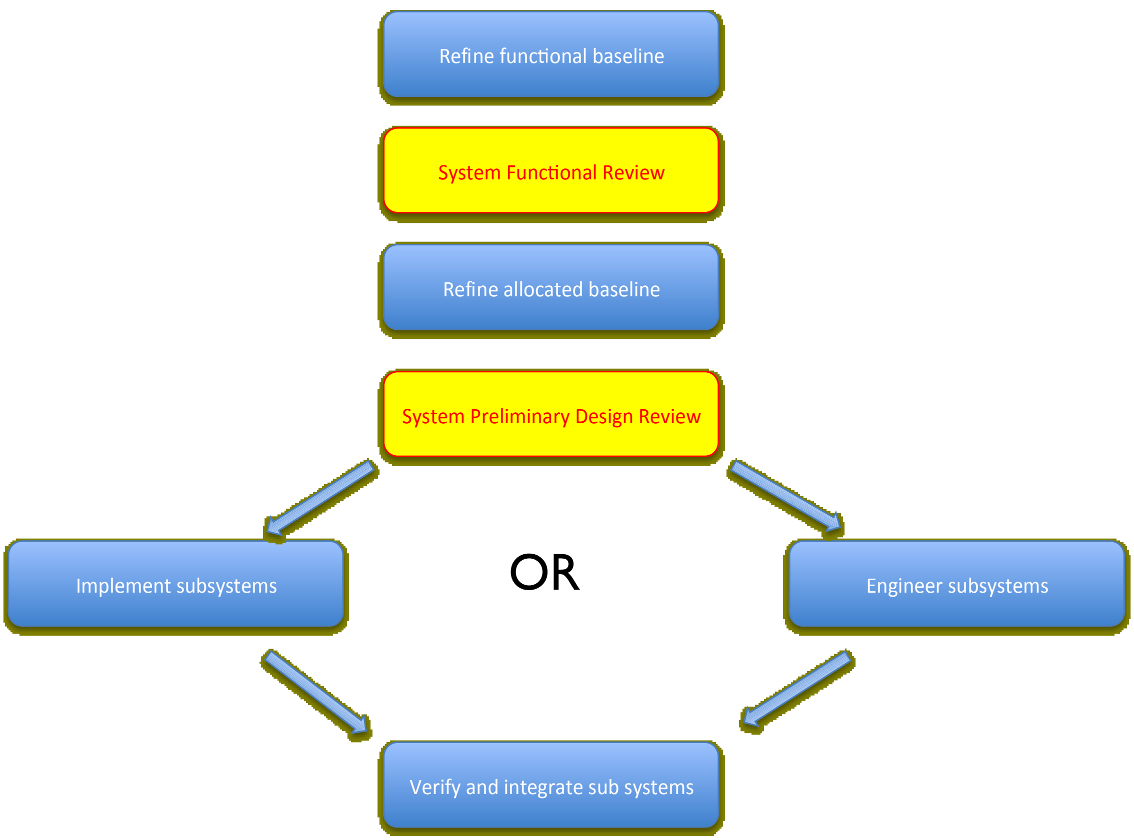

Figure 20: Decision logic at the PDR for implementing or engineering a system.

Each sub system development will follow its own V cycle. This mechanism will geometrically multiply the V cycles to be performed in parallel. This is represented by the enlarged base of the V in Figure 21. Thus, throughout this mechanism, greater the number of components, greater the thickness of the V base.

The design engineers who are members of the various diverse research institutes will produce *system design descriptions* that comply with the requirements allocated to the component during the PDR of the upper level system. The system owner will coordinate this detailed design process [5].

3.3.5.1 Detailed design products

Before and during the detailed design phase, product designer will define and study the characteristics of the elements. The following characteristics will be assessed if applicable for the hardware:

- Thermic,
- Plasma and beams,
- Fluidic,
- Electrical and electromagnetic,
- Mechanics,
- Instrumentation and Control system,
- Packaging, Handling, Storage and Transportation.

These studies will be documented through technical design reports. These reports will emphasize the analysis showing how the product satisfies its set of requirements including safety requirements. The entry point for the design description will be the *System Design Description* document which may suffice for describing the design of the component or may refer to additional descriptions like P&ID and drawings.

The identification of the technical solution might consist in identifying COTS instead of performing home made design.

In addition, and before the CDR, the *integration plan* and the *system operation and maintenance manual* for a component will have to be mature enough for proceeding to the procurement. It is crucial that the design of a component includes the required features for supporting all phases of its life cycle. COTS suppliers will have to deliver at least a similar documentation.

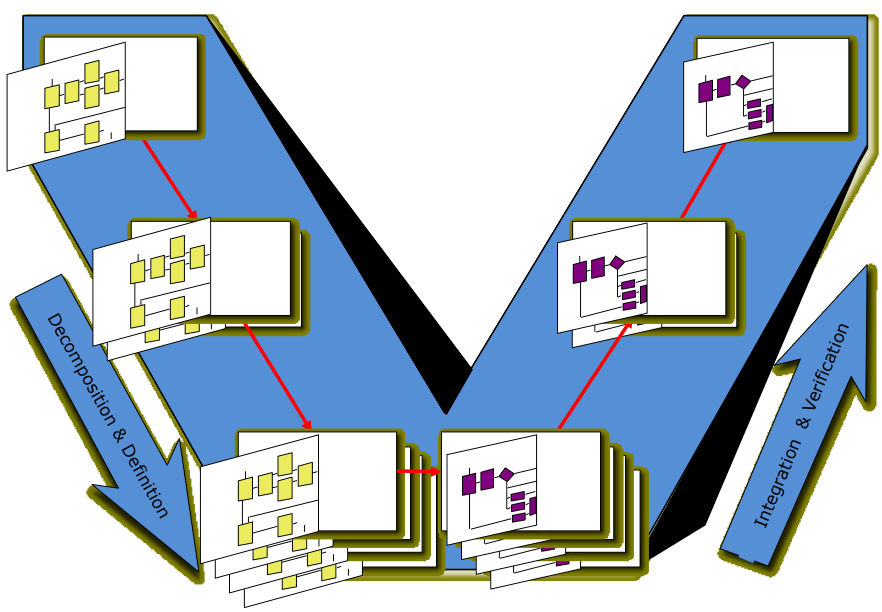

Figure 21: Illustration of the dual V aspect of the ESS development.

3.3.5.2 Engineering model policy

The development of engineering models and prototype will be commissioned in order to mitigate technical risk regarding to the performance, cost and schedule criticality. The systems which are not encompassed by the state-of-art and/or components which are repeated enough to potentially constitute a set on the critical path will be especially addressed.

3.3.6 Verification, Integration and Validation

Related standards: ISO15288:2008 Clause 6.4.6, 6.4.7, 6.4.8

3.3.6.1 Verification methods

It has to be ensured that the programme team designs and builds the systems for satisfying the requirements. Therefore during the requirements definition process, the method of verification for each requirement will be identified. Four standard verification methods are proposed to check the adequacy of the system in terms of its requirement:

- *Inspection*: visual examination of a system and associated descriptive documentation (measurement, testing data) that compares appropriate characteristics with predetermined standards to determine conformance to requirements without the use of special laboratory equipment or procedures. A review is in this category.
- *Analysis*: critical and careful evaluation of a situation or problem that shows the theoretical compliance (e.g. analytical data or simulations that show the theoretical compliance.).
- *Demonstration*: verification by witnessing an actual operation in the expected or simulated environment, without need for measurement data, additional test equipment or post demonstration analysis.
- *Test*: any program or procedure that is designed to verify that a system conforms to its requirements.

The SED is responsible for ensuring that there is a verification method for each requirement for the facility. The ESS system owners will have this responsibility for lower levels.

3.3.6.2 Verification products

Verification plan

The *System Verification Plan* documents the strategy that will be used to verify and ensure that a product or system meets its requirements. It is developed in two steps: it initially layout the verification effort, then it details the procedure that is the specific and detailed steps to be followed to perform the verification activities. The first issue for the PDR (system) might contain only the specification of the verification methods for each requirement. Versions for the CDR and TRR must contained the detailed description of the verification activities as defined below.

The verification plan defines: who does the verification; when and where it is to be done; the responsibilities of each participant before, during, and after each verification; the hardware and software to be used (and other systems if applicable); and the documents to be prepared as a record of the verification activity.

The *System Verification Plan* identifies the specific verification cases to be performed. A verification case is a logical grouping of methods for verification of functions, constraints and performance criteria (all from the system requirement specification as depicted in Figure 2) that is to be verified together. There may be several individual requirements that define a capability, and they may be verified in one verification case. The actual grouping of requirements into a verification case is arbitrary. They should be related and easily combined into a reasonable set of verification procedure actions.

Each verification case of the plan will contain at least the following information:

- A complete list of the requirements to be verified. For ease of tracing of requirements into the Verification Plan and other documents, the requirements are called in by their Id.
- Any data to be recorded or noted during the verification, such as expected results of a verification step. Other data, such as a recording of a digital message sent to an external system, may be required to verify the performance of the system.
- A statement of the pass/fail criteria. This may be just a statement that the system operates per the requirements,
- A description of the verification configuration. That is a list of the hardware and software items needed for the test and how they should be connected. Often, the same configuration is used for several tests.
- A list of any other important assumptions and constraints necessary for conduct of the verification case.
- A schedule of the activity.

Consequently, each verification case is described via four distinct sections: support environment, configuration, setup and procedure descriptions.

Verification reports

This *System Verification Report* identifies the type of verification performed and reports on the results of the verification activities. Content of this document can/should be taken from the applicable *System Verification Plan*. In this respect, each verification case of the SVP is reported in the *System Verification Report* via two sub reports: the configuration report and the results report.

The *configuration* section identifies the equipment and software that have been verified. It also identifies all equipment and software that have been necessary for the verification activity. This may include special test equipment and any external systems with an interface to the configuration under test. This section also documents the involved personnel during the verification activity. Differences with the *System Verification Plan* should be underlined.

The *results* section summarizes the purpose and results of each verification case performed in the applicable *System Verification Plan*. Special attention is paid to any verification case where a failure occurred and how the failure was resolved. This section covers:

- Verification case overview and results,
- Completed *System Verification Plan* pages annotated with pass / fail results,
- Description of each failure, if any, from the expected result called for in the *System Verification Plan*,
- Any back-up data or records related to the field procedure (could be in annex),

- Details of the resolution of each test failure, including procedure modification, software fix, re-testing and results, and required document change requests (including changes to the requirements if applicable).

The *System Verification Report* is subject to the System Acceptance Review.

3.3.6.3 Integration

Goals of the integration process

This process confirms that all boundaries between system elements have been correctly identified and specified, including physical, logical, and human-system interfaces and interactions. It confirms that interface requirements are satisfied. Interim assembly configurations are tested to assure correct flow of information and data across internal and external interfaces to reduce risk, and minimize errors and time spent isolating and correcting them.

Integration products

- *System Integration Plan*

The *System Integration Plan* describes to the participants in each integration step what has to be done. The integration team has to assemble various resources for each integration step. The *System Integration Plan* identifies the needed resources. In addition, it identifies when and where the resources will be needed.
The *System Integration Plan* is structured into two distinct parts. The first part describes how the integration activity progresses with a process specification. The second part details each step defined in the integration process. The description of each integration step should identify:

- The location of the activities,
- The equipment and/or software products to be integrated referred by the PBS Id. Initially this is just a high level list but eventually the list must be exact and complete, showing also part numbers and quantity.
- Any support equipment (special software, test hardware, and drivers to simulate yet-to-be-integrated software components, external systems e.g. tooling) needed for this integration step.
- A description of the verification activities that occur after this integration step (not in detail but traceability to the Verification Plan content must be unambiguous). This concerns the System of interest at the upper level.
- The responsible parties for each activity in the integration step.
- The schedule for each activity.

The WBS must be updated according to this activity description. This document is a mandatory input for the *critical design review* and the *system acceptance review*.

- *ESS facility 3D Model*

The Integration and Design Support Division will conduct the process for integrating all CAD models in place of their associated space slot. Coordination of all components in the ESS CAD structure will be one of the major inputs for the integration process with regular occurring forums, to verify and control the fit and position of all components in the facility. The IDSD will set up the ESS CAD structure. This model will enable conflict resolution and support the development of the site infrastructure and support the configuration management process.

- *Conformity and non conformity reports*

Integration activities will result in the released of Conformity or non-conformity reports by the programme team during the construction phase as defined in the CMP [6].

3.3.6.4 Validation

Validation process

Downstream to the verification and integration activities, the validation process will make use of the ESS system under its operational conditions. The main validation activity will be the commissioning of the facility. Intermediate demonstrations will be performed and will follow integration stages.

In parallel of the validation, the transition phase will be conducted through ESS AB staff training, especially the ESS AB staff who will contribute to the validation activities for the operation and maintenance.

Validation plan

A validation plan will be established by the SED and once released, it will be placed under configuration control. This plan will identify the strategy for validating ESS based on the stakeholders' requirements specified in the ESS concepts of operation document.

3.3.7 Scheduling and Costing support

The SE process will support the costing of the ESS construction by performing life cycle cost analyses as introduced in section 3.3.4.5. Indeed, the proposed engineering documentation associated to a system as developed via the SE process, will provide detailed information which is required for establishing precise WBS from the construction to decommissioning of the facility. However, the process will not cover indirect cost like overheads. If this regard, the provided life cycle cost is a proportion of the through life cost which is the target value for project office activities.

These evaluations will scrutinize all relevant costs for a product/component over a given period of its life cycle. For COTS products, it will only seek to evaluate the cost for acquisition (specification and manufacturing follow-up if needed), operation and maintenance, and retirement. For other products, the life cycle depicted in Figure 3 will be used.

More specifically, it will be determined the number of operational units, test units, and spares to be procured (see 8.1). Thus, parameterized cost data will be developed within the ESS platform library. For each stage of the life cycle, component owner will evaluate the requested manpower for each stage of the entire programme. These estimates will flow up and be complemented by verification and integration activities cost.

3.3.8 System control

Systems engineering control is a collection of methods used to manage the project configuration, risks, subsystems and external interfaces, as well as to track both the ESS facility performance as a whole and the progress of the facility development.

3.3.8.1 Configuration management

The ESS Configuration Management - CM – system functions as a library for documentation control, access, and dissemination. The ESS Configuration Management Plan [6] details the CM processes including the various boards and the responsibilities, the supporting documents and board chairmanship. This document refers to the change control process [12].

3.3.8.2 Traceability management

Traceability is concerned with documenting the life of a configuration item and providing bi-directional traceability between various development artefacts. Its purpose is to facilitate:

- The overall quality of the product(s) under development;
- The understanding of product under development and its artefact; and
- The ability to manage change.

The artefacts shall be stored and secured during the whole life cycle of the facility for supporting change impact assessment at any point in time. The satisfaction of this requirement shall be supported by a Product Lifecycle Management – PLM – platform. As a complement to the Figure 2, the Figure 22 shows the relationships within the ESS meta-model populated by descriptions, each derived from a specific viewpoint.

3.3.8.3 Peer and internal technical reviews

The SED will also utilize peer reviews to enhance the quality of the SE process deliverables. Peer reviewers will be *ad hoc* external experts called in as needed.

3.3.8.4 Technical Performance Measure (TPMs)

The SET will establish a set of TPMs to track critical performances parameters throughout the development of the facility. These TPMs are parameters that will impact the science, cost or/and schedule if they exceed/are inferior to critical values. These parameters are either directly measurable and/or derivable from modeling. They will be tracked as integral to the systems engineering process to ensure that the ESS objectives are met. Critical and state-of-art TPMs will be considered. A critical TPM measures the achievement of a requirement that doesn't necessarily imply to go beyond the state of art, such requirement being nevertheless one of the major expectations. For example, TPMs for cost requirements are assumed critical. A state-of-art TPM measures the capacity to innovate as expected. A TPM may be both critical and state-of-art.

The TPMs will be monitored by the SED and reported to the programme team. The system-level metrics are flowed-down and budgeted to the subsystems by the SET. The top-level TPMs for the ESS facility are selected by the PMO and approved by the EPG. Proposed TPMs for ESS are:

- The ESS facility life cycle cost (critical),
- The ESS facility reliability (95%) (critical and state-of-art),
- The neutron source peak brightness for cold neutrons (critical and state-of-art),
- The beam time for users (critical).

Each TPM will consist of a planned value and a current value. Variances between planned values and current values will reflect the risk throughout the programme.

The TPMs are set up in the *system requirement document* and approved during the functional review by the owner of the SoI.

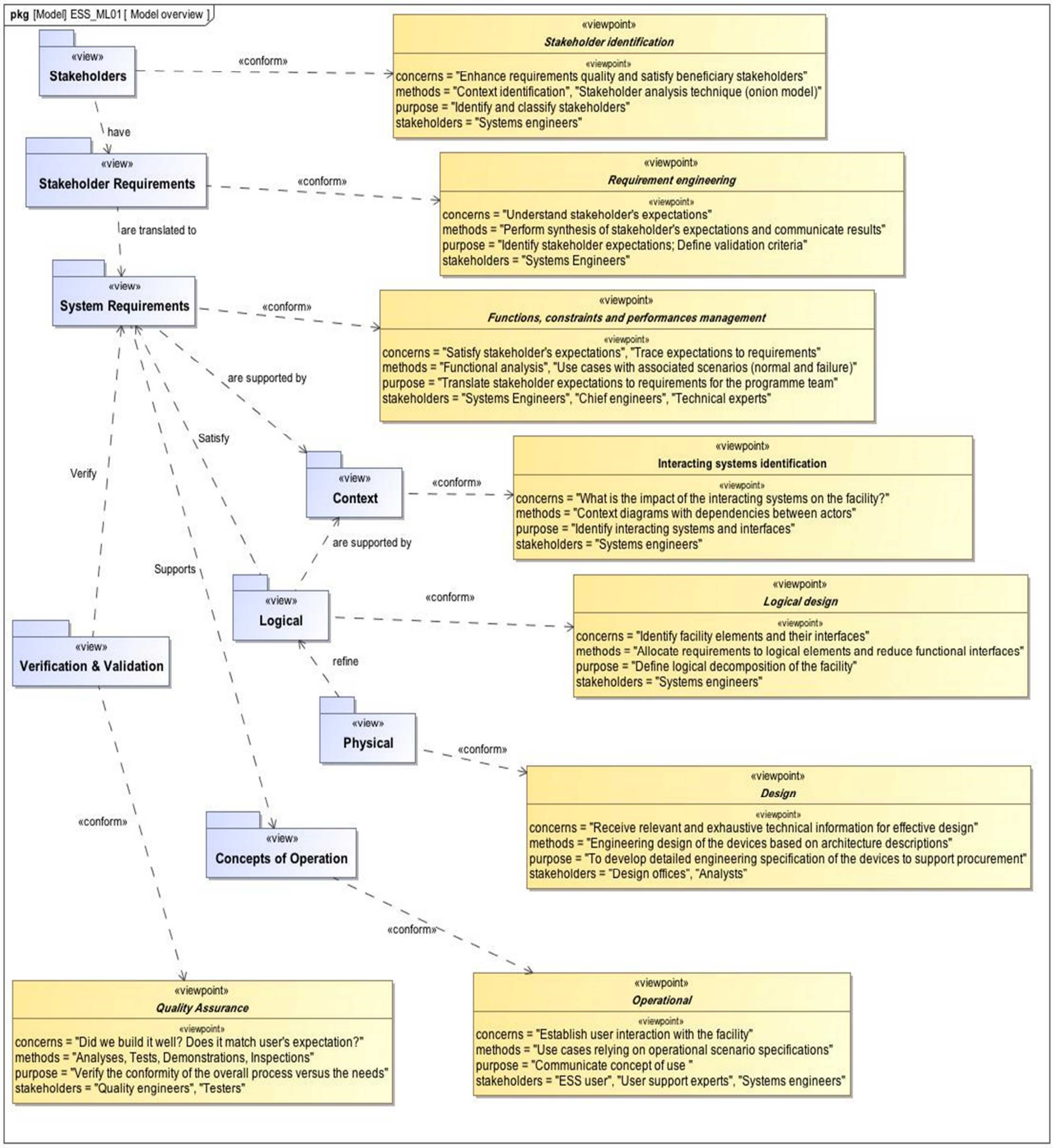

Figure 22: Architecture of the ESS meta-model (technical).

3.3.9 Communication

3.3.9.1 Quarterly technical interfaces meetings

The SED will conduct quarterly face-to-face meetings. These meetings are intended to bring ESS systems together for assessing the status of the ICDs at level 2.

3.3.9.2 Collaborations

One of the major challenges of the ESS construction project is to coordinate the contributions by teams from several geographically diverse organizations and cultures. An efficient coordination goes through a common vision of the methods to be implemented for the ESS construction. Communication between the partners is a crucial mean to obtain this common vision.

ESS representative persons to the collaboration boards – CBs - will communicate to the CB members the content of the ESS engineering plans. These communications will emphasize the expected outcomes and the benefits for the partners to implement the proposed plans. Throughout the ESS construction, ESS representative persons will communicate on the progress of the technical activities.

3.3.9.3 SE activities web site

The ESS SE portal will provide access to different useful links for the SE team and many ESS model reports. The major ESS model report will the ESS technical configuration navigator that will provide to any member of the programme team the access to the ESS physical and behavioural descriptions. This virtual model will therefore implement an on-line and centralized approach to the publication of technical data.

3.3.9.4 SES reporting to SED

The Systems Engineers for ESS systems will report the progress of the SE activities for their part to the SEM. In particular, the requirement definition and architecture definition progresses, in accordance to the SEMP, will be communicated to SEM during the construction phase, TPMs and the number of initiated change requests and non-conformities sheets will be reported. These reporting process will be based on weekly meetings during the construction phase.

3.3.9.5 SED reporting to EPG and CCB of the programme

The SEM will report the progress of the SE activities to the EPG and the CCB of the programme. In particular, the requirement definition and architecture definition progress, in accordance to the SEMP, will be communicated to EPG during the construction phase. TPMs will also be an essential tool to report the quality of the implementation and the technical processes together with the number of initiated change requests and non-conformities sheets.

4. SYSTEMS ENGINEERING WORKING GROUP PRINCIPLES

4.1 SE team

The ESS facility construction presents many engineering challenges. The following issues contribute to these challenges:

- Complex interactions between subsystems,
- A high reliability is required, and
- Engineering activities are occurring across the globe.

The system perspective of the ESS is essential throughout all phases of the lifecycle. Each engineer and scientist must know and understand the effects produced by their subsystem with in the overall system. Easing these interactions is the mission of the System Engineering Office.

In this context, the SEM will set up a SE Team. This SET will orchestrate the evolution of the ESS technical baseline throughout all phases of the lifecycle by:

- Maintaining the SE process,
- Defining the associated management plans in line with the Program Plan,
- Supporting the programme team members for developing the engineering documentation,
- Auditing the engineering documentation.

The SEM chairs the SET. It is comprised of the SED members, systems engineers of the ESS systems and ad hoc engineers who will be called in as needed.

The systems engineering responsibility may be delegated to a lead engineer as needed. For example, lead engineers might relay the SE function from level 4 to lower level.

4.2 Cross-functional working groups

Cross-functional working groups will be created for addressing specific issues as needed. The charge and composition of a cross-functional working group will be submitted for approval to the CCB of the programme. Cross-functional working groups will be formed and dismantled as needed. The chairman of a cross-functional working group will report to the CCB of the programme.

4.3 Day to day working groups

Working groups will also be created on a day-to-day basis for supporting analyses (risk, functional breakdown, FMEA, etc). The participation of experts to these workshops will be crucial for ensuring that the developed artifacts are technically realistic and thus the transition to the detailed engineering will be seamless.

5. SYSTEMS ENGINEERING MANAGEMENT

5.1 Systems engineering office

The Systems Engineering Office is organizationally located in the ESS Machine Directorate. The SED is responsible of the definition and the maintenance of the technical processes for the ESS programme [1]. It is responsible for establishing the overall framework and procedures for the management of the ESS technical requirements, design process and verification process.

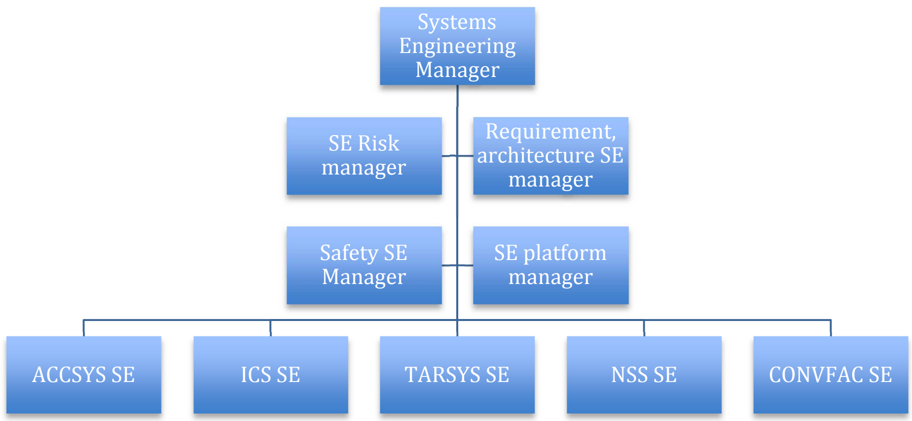

Figure 23: The SED organization chart and the SE for each project.

Through the SE process, the SE team will support the programme for developing the technical baseline and verify its cohesiveness. The SE team will make sure that top-level product attributes are still in scope as the construction phase progresses.

5.2 Roles and Responsibilities

5.2.1 The SED

5.2.1.1 The Systems Engineering Manager

The SEM is the chairman of the SE team and is responsible for the overall management of the ESS Systems Engineering activities. The SEM is responsible for facilitating the resolution of systems engineering issues between ESS systems as well as reporting progress to the program management. The SEM reports TPMs' status to the CCB of the programme and the EPG.

He/She is responsible for orchestrating the definition of the technical baseline by defining and maintaining the ESS technical processes.

The SEM defines and maintains the Systems Engineering Management Plan, the Configuration Management Plan, the Interface Management Plan, the ESS Integration Plan and the ESS Validation Plan.

5.2.1.2 The SE Risk manager

The SE Risk manager is responsible for performing the Risk Management Plan for the technical risk. He/She is also responsible for coordinating all technical risk management activities, including documentation, monitoring and action plans. He/She is a member of the PMO.

5.2.1.3 The Requirements, architecture and RAM SE manager

The Requirements and Architecture and RAM Systems Engineer is responsible for providing guidelines and support for the ESS technical requirements flow-down.

He supports the Systems Engineers of the projects for breaking down requirements, concepts of operation and architecture.

He is also responsible for maintaining the engineering documentation at the facility level: ESS concepts of operations document, facility requirements document, Facility Architecture Specification, and the ESS Verification Plan.

He initiates and supports the maintenance of the ICDs at level 1 and 2.

5.2.1.4 The Safety SE manager

The Safety SE manager –SSE- is responsible for providing guidance for requirements elicitation for Safety, Security, Health and Environment. The SSE supports the design engineers for the safety requirements allocation to components. The SSE will conduct the audit process for product specifications related to safety.

The SSE will act as the liaison officer between the SED and the Safety, Health & Environment division.

The SSE is also responsible for training and sensitising the ESS personnel to safety. In this framework, the SSE will set up and execute a training plan.

5.2.1.5 The ESS platform library manager

The ESS platform library manager is in charge of the implementation and maintenance of the SE platform library. He/she is responsible for the SE software definition and deployment. He/she provides a hot line service for the SE team.

He/she is a member of the ESS AB/ IT division.

5.2.2 Other teams and offices

5.2.2.1 The Systems Engineer for an ESS project

The Systems Engineer for an ESS project is a member of the SE Team. He/She is also responsible for maintaining the operation concepts document, system requirements documents, and the system verification plan for level 2 and lower. The SEP will report to the SED the progress of the SE implementation for his/her systems. The SEP will report to the Project Manager of an ESS system the results of the SE implementation.

5.2.2.2 The Integration and Design Support Division

The ESS Integration and Design Support Division organizationally located in the Machine directorate will be responsible for:

- CAD Integration:
    - Collect and validate the different CAD models;
    - Check the interfaces and inform the contributors of conflicts;
    - Ensure the general assembly of the facility;
    - Define the global facility virtual 3D model.
- Assistance:
    - Assist the technical group for the CAD validation activities;
    - Share concepts within the collaboration,
    - Support the conventional facilities project for product integration.
- Management:
    - Specify to the partner institutes the CAD systems management plan (CAD procedure, CAD manual, 3D model configuration, interfaces);
    - Specify to the partner institutes the format of the 3D models to be submitted;
    - The space slot allocation per product (type and dimensions),
    - Manage the sub contractors and specify the internal assistance for CAD issues.
    - Develop and maintain the design process defining activities between a PDR and a CDR.

5.2.2.3 The Lead engineer

The lead engineer might be assigned for relaying Systems Engineering activities deployed by a SE for a project at any level.

5.2.2.4 The System owner

He/She is the person **responsible for the delivery of a verified system with its associated documentation** as defined the PMO. The system documentation includes the deliverables subjects to the design reviews as described in section 3.2.2.9.

5.2.2.5 The design engineer

He/She is an expert developing system design descriptions.

6. SYSTEMS ENGINEERING PRODUCTS

6.1 Guidelines

During the preconstruction and the construction phases, the SED will draft guideline documents to support the technical processes. These documents will be part of the Quality documentation and will be established with the Quality manager.

These and other guidelines documents may be created and updated by integrating the feedback of the programme participants.

6.2 Templates

The SED will provide a series of template documents for supporting the SE process execution. This series of templates consist in:

Template	DMS reference
Form to aid in performing a FMEA	ESS-000xxxx
Form to aid in performing a MTA	ESS-000xxxx
System Requirement Document	ESS-0004789
Concept of operation for a system	ESS-0004790
System Verification Plan	ESS-0004794
System Verification Report	ESS-0004795
System Architecture Specification	ESS-0004791
Interface Control Document A2B	ESS-0004793
Interface Control Document A2x	ESS-0004792
System Integration Plan	ESS-0004796
Component Operation and Maintenance Manual	ESS-0004798
System Design Description	ESS-0004797

Each template contains guidelines for supporting the development of the content for each section.

6.3 Systems engineering documentation tree

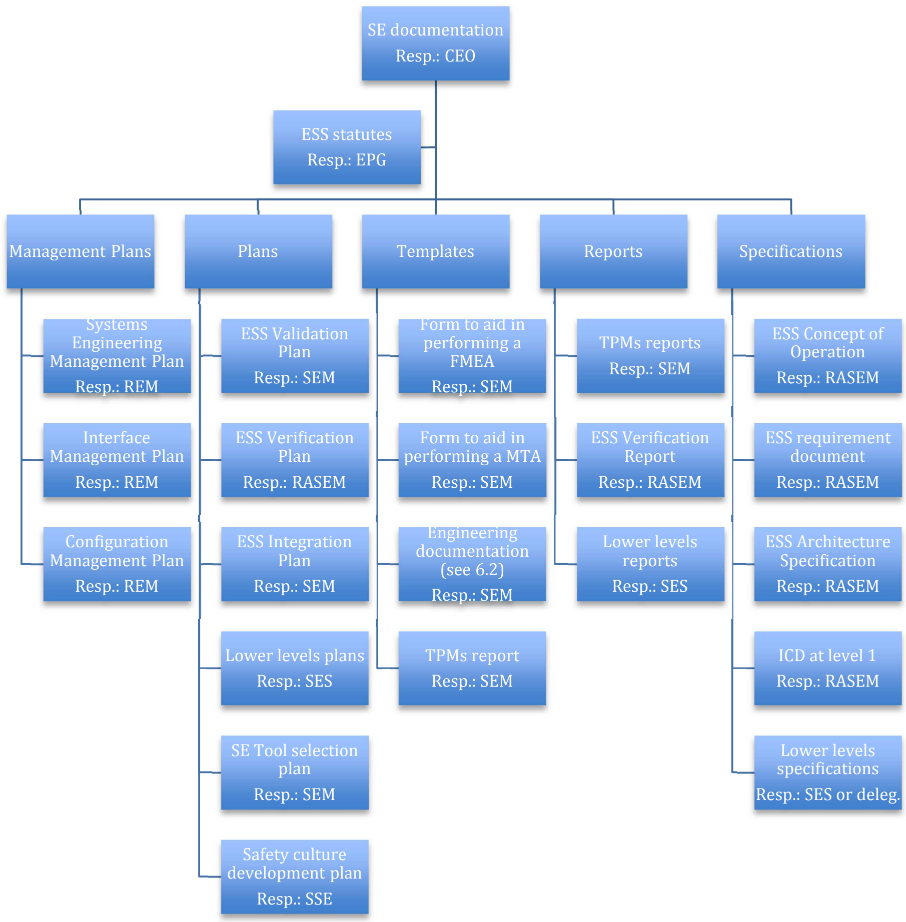

Figure 24: ESS Systems Engineering Documentation Tree.

7. SYSTEMS ENGINEERING TOOLS AND META DATA

A Systems Engineering Framework and Platform Library is being developed by the IT division for satisfying development process needs. The purposes of such platform library are:

- To provide a set of steering documents to create open, generic, independent standards in order to facilitate that all stakeholders and participants can effectively contribute to the fulfilment of ESS,
- To support the SE activities and more specifically:
  - Configuration management,
  - ESS facility modelling (behaviour, structure),
- To support cost and scheduling activities by implementing a repository of work products.

An important part of the Model Based Systems Engineering activities is communication to stakeholders of the product descriptions (interfaces and internal structure), trace links with their logic and many behaviour descriptions.

The ESS platform library tools will implement an ESS description model developed with the System Meta Language (SysML). SysML is a language for communication that emphasizes the SE domain. Utilization of the SysML language will allow developing parametric modelling of the ESS facility which will support trade studies and simulation of change propagation to sustain the configuration management. SysML, emanating from the INCOSE and the OMG, is being utilized more and more by SE teams worldwide that share their experience through forums. These forums will help the ESS development to capitalize on experience gained by other teams.

7.1 Architecture and data export

The Figure 22 depicts the architecture of the ESS meta-model. The ESS meta-model will embed various views of the facility like block diagrams, internal block diagrams, use cases, requirements tree, activity diagrams and parametric diagrams. The SysML model of the ESS is a part of the overall ESS meta-model. These model artefacts will describe the ESS facility from different viewpoints and will define a structural and behavioural model. This model or part of this model might be instantiated for studying alternative baselines to support the trade studies and change impact assessment. The parameters of an instance will be exportable to CSV tables. CSV tables will enable a large sharing of the stored data among the programme team members and independency from a proprietary storage solution.

A software package will support the development of the ESS meta-model. This software package will be capable of:

- Generating traceability matrices,
- Extracting any part of the model through reports (office or html documents), and
- Exporting the model for permitting navigation from a web browser.

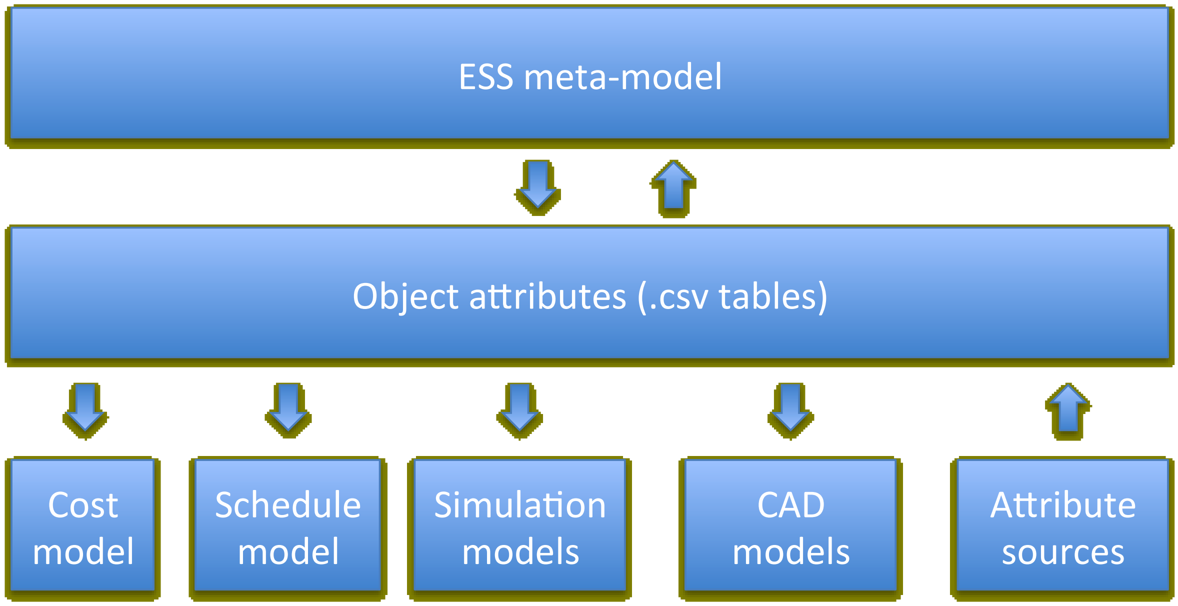

Figure 25: Architecture of the ESS platform.

7.2 Object attributes

7.2.1 Requirements

Attribute name	Expected information
Id	Unique identifier
Name	Name of the parameter defining the performance
Text	Textual description of the requirement
Responsible	Requirement owner
Source	Trace to a source document, DMS Id shall be mentioned.
Verification Method	Specification of one of the fourth possible verification method
Priority	3 levels: 1. **Essential** requirements that must be included in the system 2. **Useful** capabilities that would reduce system effectiveness if left out

Attribute name	Expected information
	3. **Desirable** capabilities that make the system more desirable to certain stakeholders.
Related risk	When the requirement is derived from a risk analysis. The related risk Id shall be mentioned.
Reviewed by	Name of the last reviewer
Operating Mode	When the requirement is specific to an operating mode for the SoI, the name of the mode shall be specified
State	When the requirement is specific to an ESS state, the name of the state shall be specified
Min value	The expected minimum value for the parameter of interest
Nominal value	The expected nominal value for the parameter of interest
Max value	The expected maximum value for the parameter of interest
Unit	S.I. units for the value of interest specification.
Condition	When the performance is specific to certain conditions (normal or off-normal), the condition is described (e.g. limited time, for a specific context)
Status	• In Work, • In review, • Approved, • In revision, • Released, • Obsolete.
Category	• Functional • Constraint • Safety • Electrical • Environment • Interface • Regulatory • Operational • Maintenance • Structural • Radiation safety • Conventional safety

Attribute name	Expected information
	• Testability • Supportability • Usability • Instrumentation and control • Security
Version	Current version of the requirement.

7.2.2 Product (PBS node)

<table>
<tr><th>Attribute name</th><th colspan="5">Expected information</th></tr>
<tr><td>Name</td><td colspan="5">Name of the system</td></tr>
<tr><td>Long Name</td><td colspan="5">Unique identifier as defined in [6]</td></tr>
<tr><td>Description</td><td colspan="5">Textual description of the product</td></tr>
<tr><td>Comment</td><td colspan="5">Text field for leaving a comment.</td></tr>
<tr><td>Responsible</td><td colspan="5">System owner</td></tr>
<tr><td>Functions</td><td colspan="5">List of functions as defined in the functional breakdown allocated to the systems. This feature might be use for specifying the operating modes for the SoI.</td></tr>
<tr><td>Related risk</td><td colspan="5">When the system is addressed by a risk analysis. The related risk Id shall be mentioned.</td></tr>
<tr><td>Related Task</td><td colspan="5">Specify the Id of the WBS element that will deliver the System. This feature supports change impact assessment.</td></tr>
<tr><td>Reviewed by</td><td colspan="5">Name of the last reviewer</td></tr>
<tr><td>Maintenance policy</td><td colspan="5">Repair or Discard</td></tr>
<tr><td rowspan="2">Parameter</td><td>Name</td><td>Min</td><td>Nominal</td><td>Max</td><td>Unit</td></tr>
<tr><td>Parameter's name</td><td>Minimum value for the parameter of interest</td><td>Nominal value for the parameter of interest</td><td>Maximum value for the parameter of interest</td><td>S.I. units when applicable</td></tr>
<tr><td>Status</td><td colspan="5">In Work,
In review,
Approved,
In revision,
Released,
Obsolete.</td></tr>
<tr><td>System category</td><td colspan="5">Safety
Security
Radiation safety</td></tr>
</table>

Attribute name	Expected information
	• Conventional safety • Electrical • Actuator • Sensor • Test Equipment • Maintenance equipment • Structural • Instrumentation and control • Tooling • Packaging • Vacuum • Mechanical • Power source
Version	Current version of the product node description.

The parameter attribute can be multiplied as needed for specifying e.g. the mass, power demand, etc. The parameter values can be either static or parameterized. Some parameters are mandatory and they are depicted in the table below:

Parameter category	Parameter description	
	Name	Unit
Schedule	Design duration	h
Cost	Design effort for the period	FTE
Cost	Design cost	€
Cost	Acquisition cost	€
Schedule	Acquisition duration	h
Cost	Acquisition effort for the period	FTE
Cost	Verification fixed cost	€
Cost	Verification running cost	€/h
Schedule	Verification duration	h
Cost	Verification fixed effort for the period	FTE.h

Parameter category	Parameter description	
Cost	Verification running effort for the period	FTE
Cost	Integration cost	€
Cost	PHS&T cost	€
Schedule	Integration duration	h
Cost	Integration effort	FTE
Cost	Operation running effort	FTE
Cost	Operation running cost	€/h
Cost	Operation fixed effort per year	FTE.h
Cost	Operation fixed cost per year	€
Schedule	Operation duration per year	h
Cost	Maintenance effort	FTE
Schedule	Maintenance duration per year	h
Cost	Maintenance fixed cost per year	€
Cost	Disposal effort	FTE
Schedule	Disposal duration	h
Cost	Disposal cost	€
RAM	Mean Time To Repair	h
RAM	Mean Time To Mission Failure	h
RAM	Mean Time To Failure	h

It should be noted that the cost values must not include the personnel cost. The personnel cost will be derived from the effort value and the duration of the task.

7.3 Communication outputs

The ESS SE web [14] site will be the entry point for accessing to the SE communication materials. The ESS SE portal will provide access to:

- Indico links to SE workshops and other SE events,
- Internet link to the Document Management System (CHESS),
- Internet links to the ESS model navigator (see Figure 26),
- Internet links to SE process description,
- Internet links to SE related web sites,
- Link to the ESS glossary.

The ESS model navigator will bring to the user attention the established traceability between the model elements through hypertext links. It will be possible for any programme participants to comment any element for supporting a collaborative development of the model.

The ESS model reports will be deployed and maintained by the SE platform manager member of the IT division.

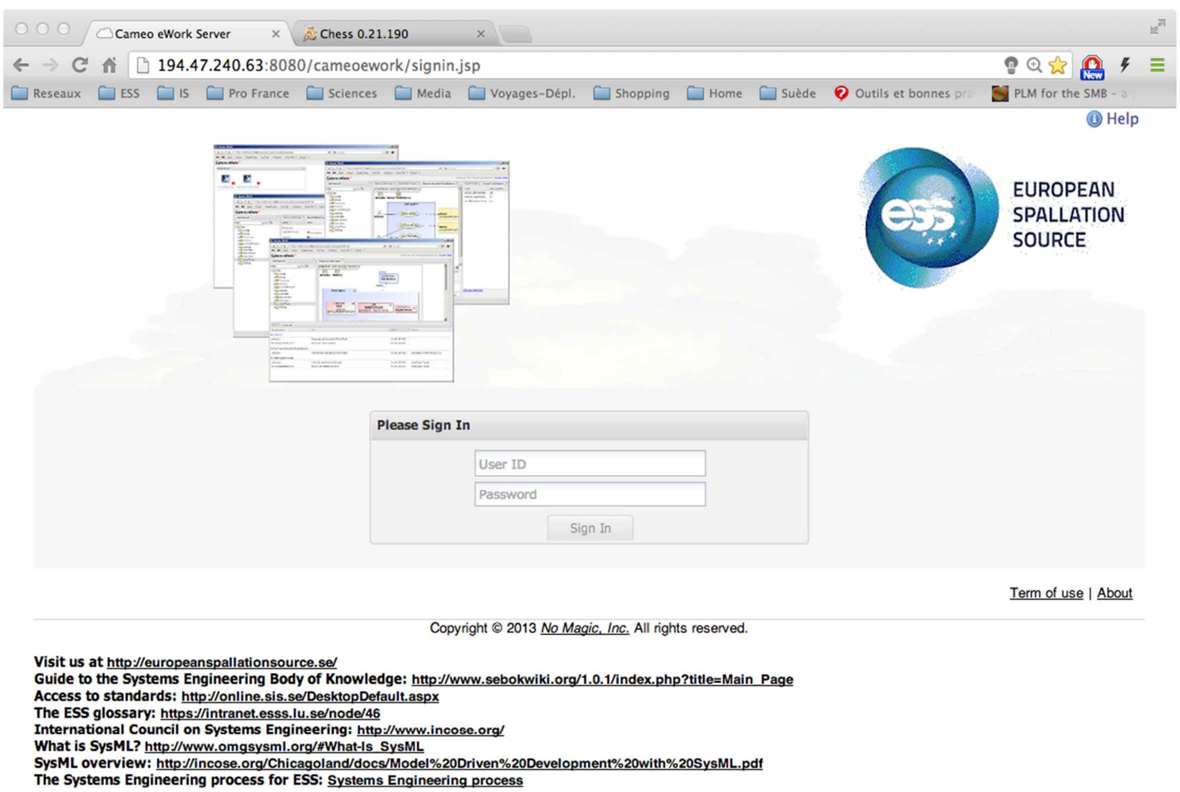

Figure 26: View of the home page of the ESS model navigator.

7.4 Plan for tool selection

The implementation of the ESS platform and its maintenance will rely on a set of in-house or/and commercial software tools. To support the tool selection and the implementation of the platform library, a plan and a pilot will be defined by the SED. This pilot will consist of a test case to establish the adequacy of the candidate tools to support the ESS systems engineering processes. The pilot will be defined in the Systems Engineering Tool Selection Plan.

8. OTHER SYSTEMS ENGINEERING ACTIVITIES

8.1 Integrated Logistic Support

Integrated Logistics Support – ILS - is a set of techniques for identifying, during the system design, from the identification of user need and the conopts, the support system that will be associated with the facility. When ILS is designed, it may influence the definition of the main system for better operational availability, while controlling the overall cost. This ILS definition is a crucial tool to prepare for the handover phase.

The main topics of ILS not addressed so far in the process described in this document are:

- Failure Reporting, Analysis an Corrective Action System,
- Facilities management,
- The Packaging, Handling, Storage and transportation,
- Spare components,
- Personnel training,
- Obsolescence management,
- Software support.

Analyses of ILS will be conducted to determine the support system that will be the most effective for an optimized total cost preserving the operational availability. The necessary adaption of the SE process for addressing these above topics will be the subject of future revisions of this document.

8.2 Standards and terms

8.2.1 Standards and Units

To avoid any failure due to the utilisation of different units for a common parameter by different partners, the ESS System specifications will use the international system of units. The conformity of the technical notes and performance requirements will be part of the audits as defined in the CMP [6].

To support the requirement definition, a list of the applicable standards will be defined and maintained by a specific cross-functional working group.

8.2.2 Glossary

To limit confusion during the exchanges of information between collaborators, a glossary will be set up and maintained to provide definition of the major words and terms potentially or effectively utilized by the programme participants.

Appendix A

(ESS systems engineering process map)

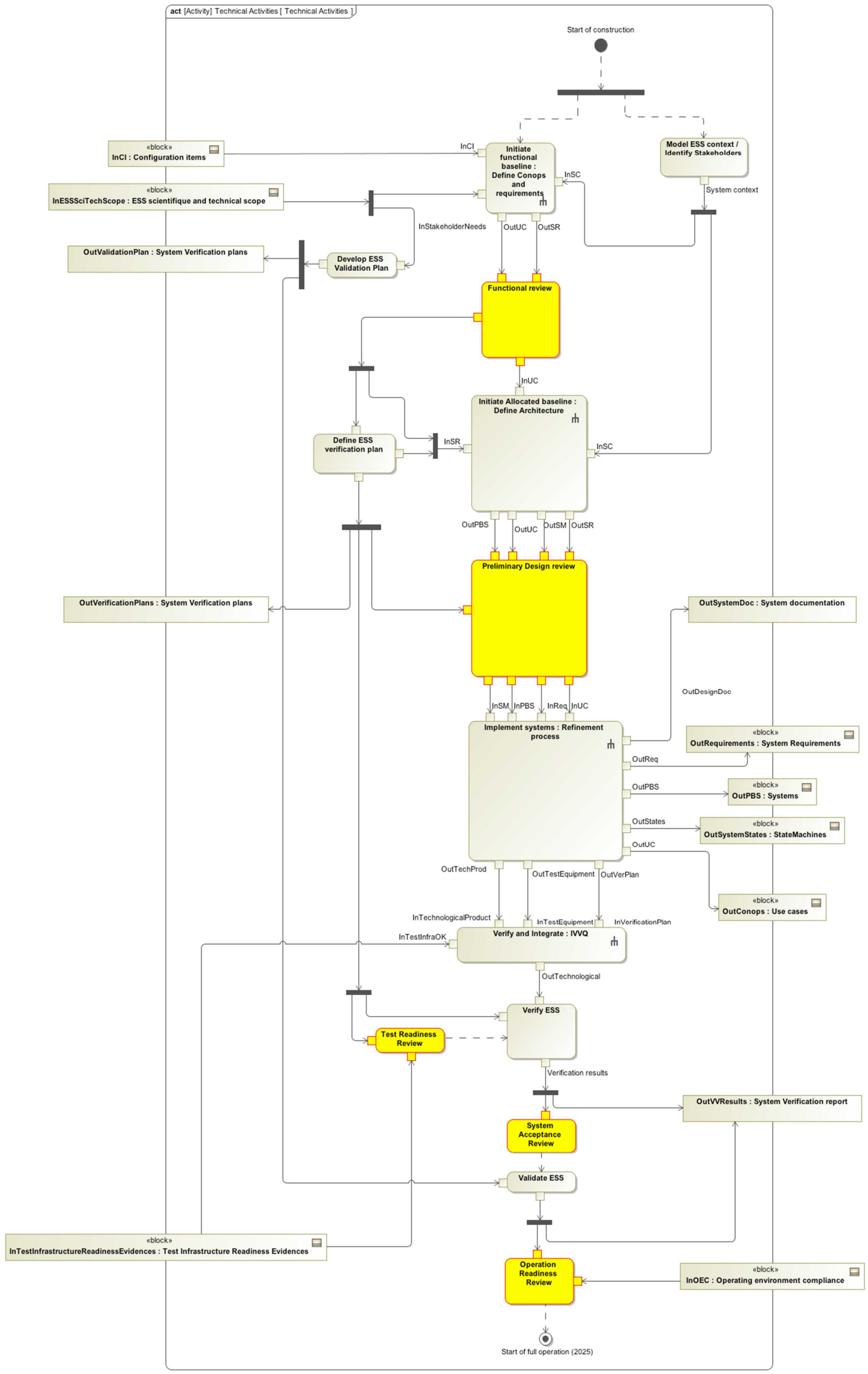

Figure 27: Technical activities description.

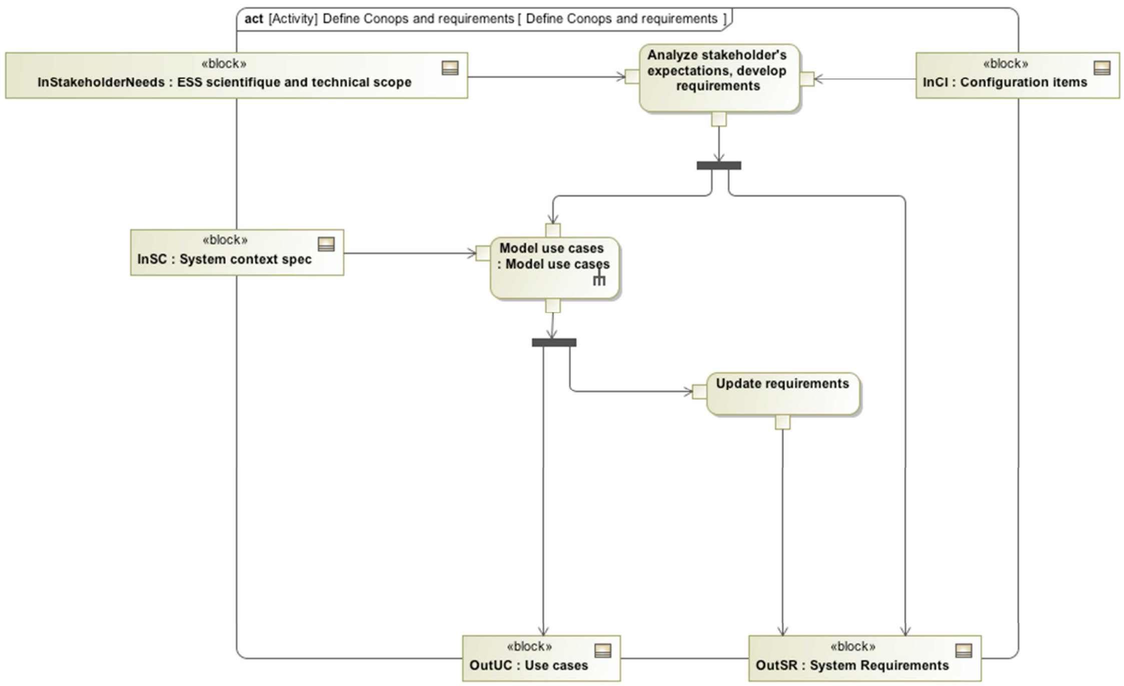

Figure 28: Define Conops and requirements activities description.

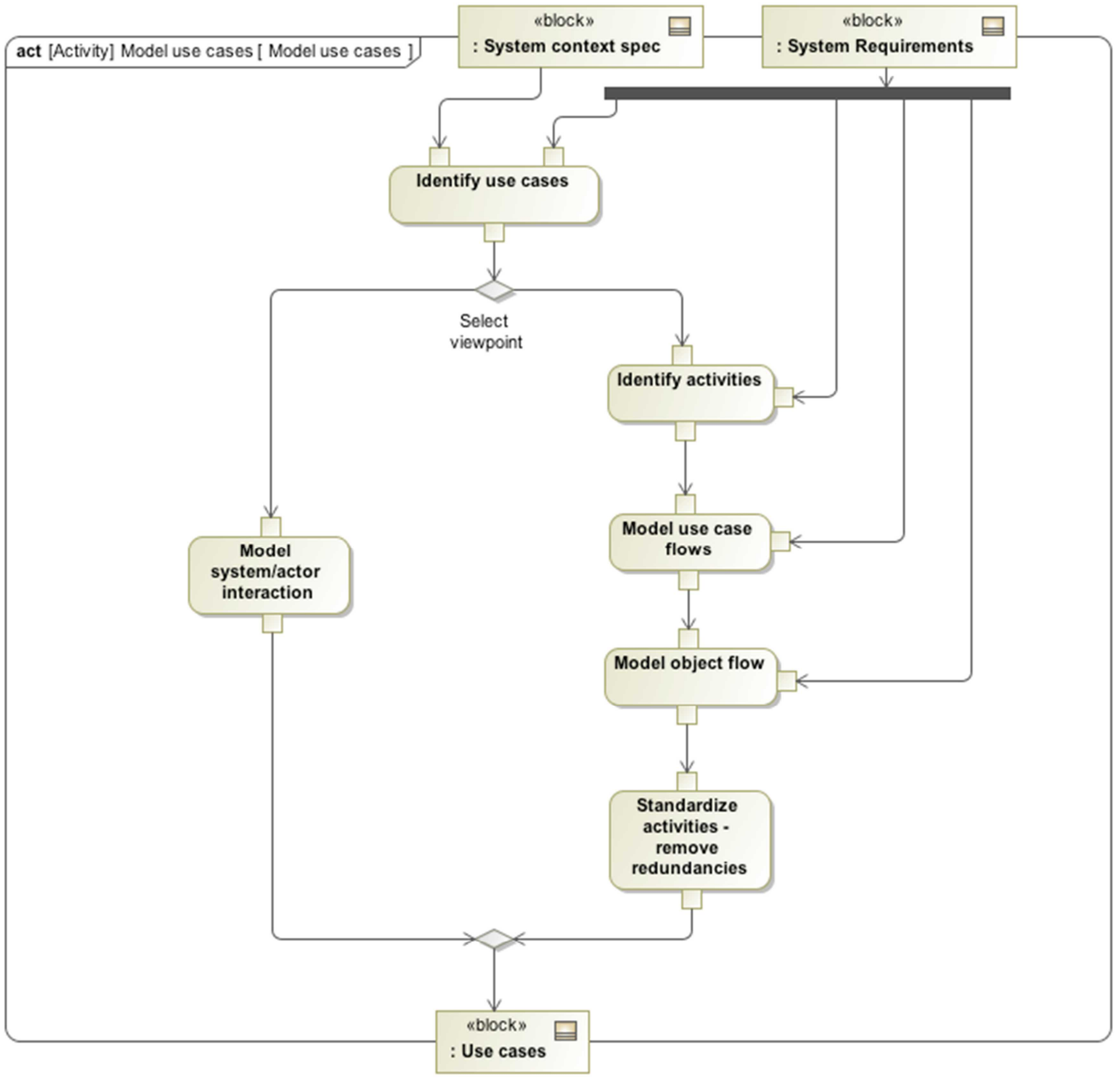

Figure 29: Model use cases activities description.

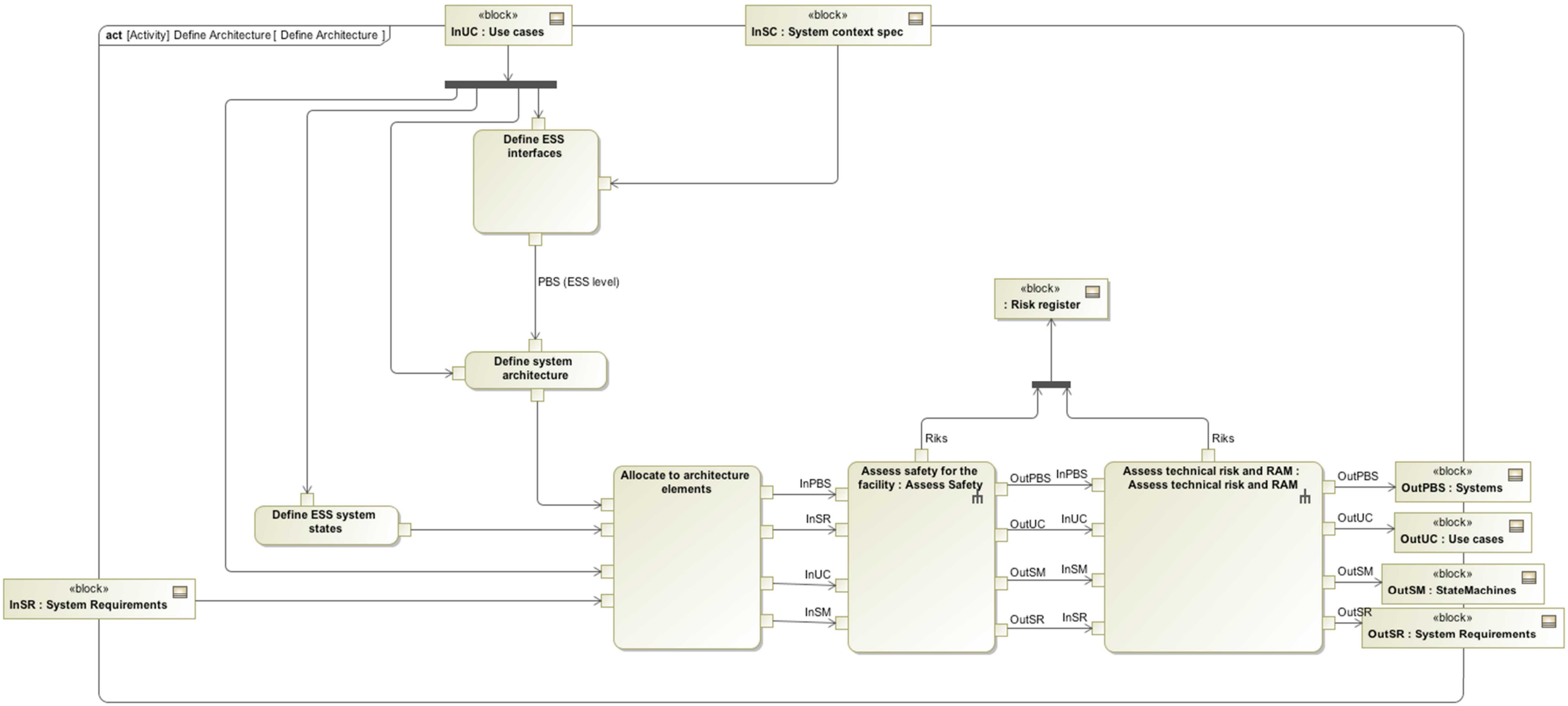

Figure 30: Define architecture activities description.

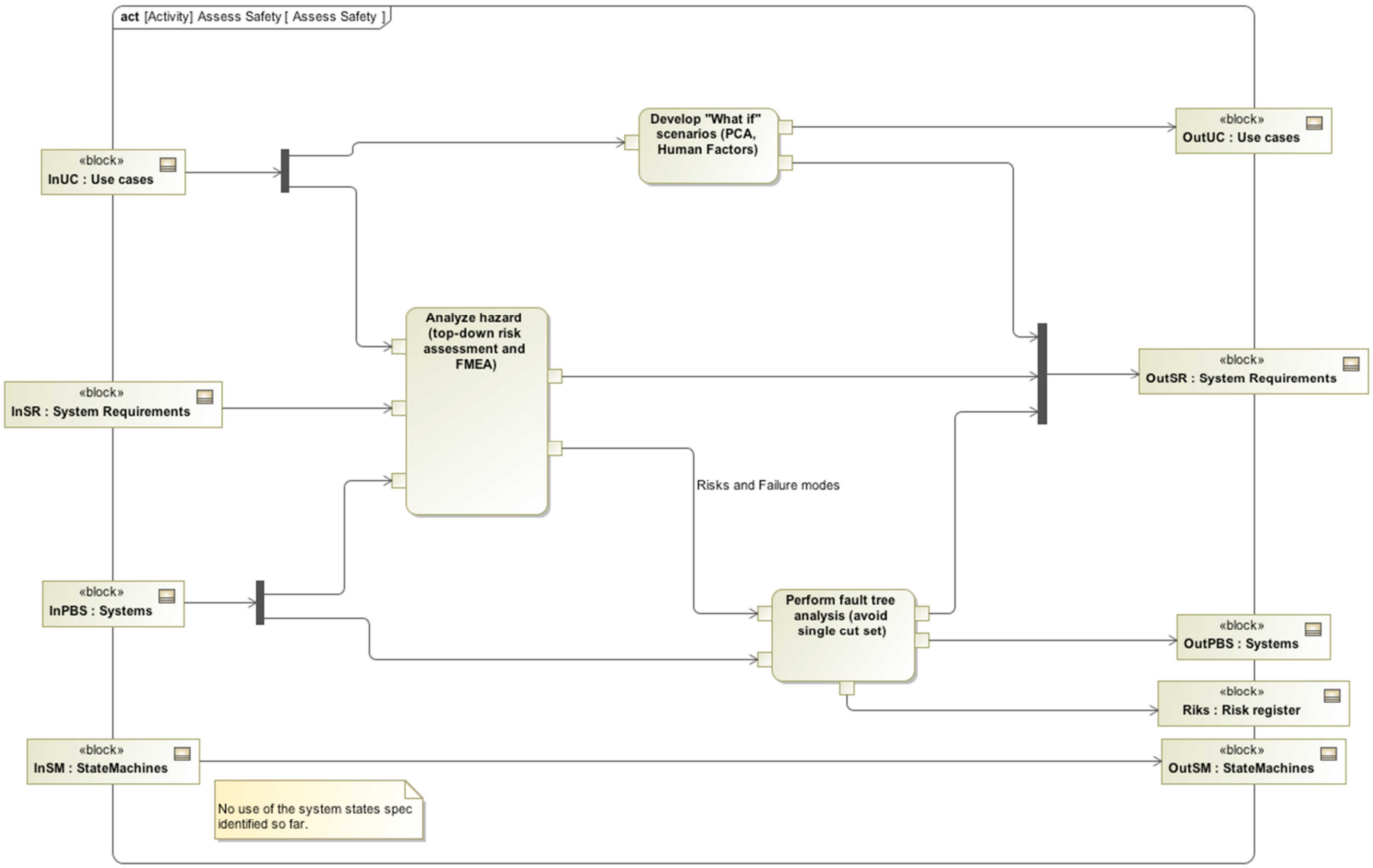

Figure 31: Assess safety activities description.

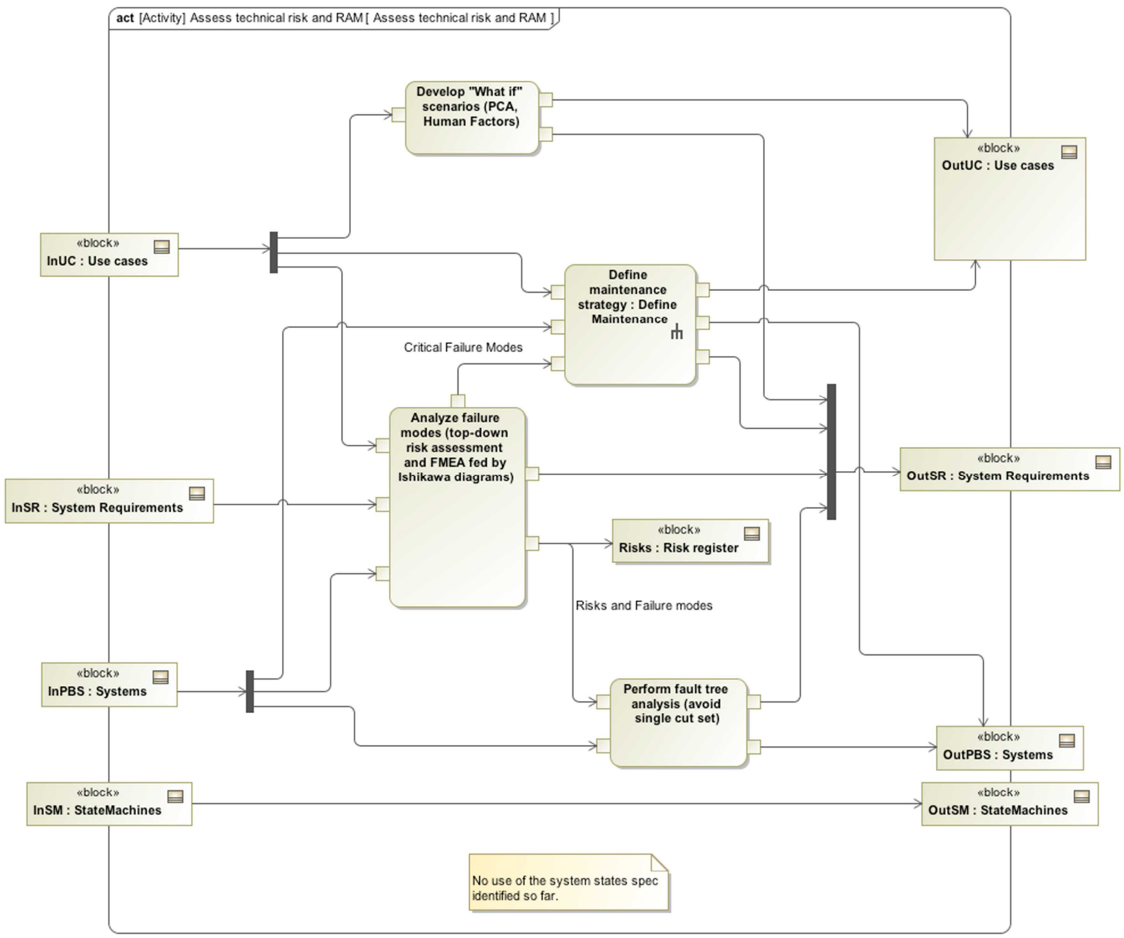

Figure 32: Assess technical risk and RAM activities description.

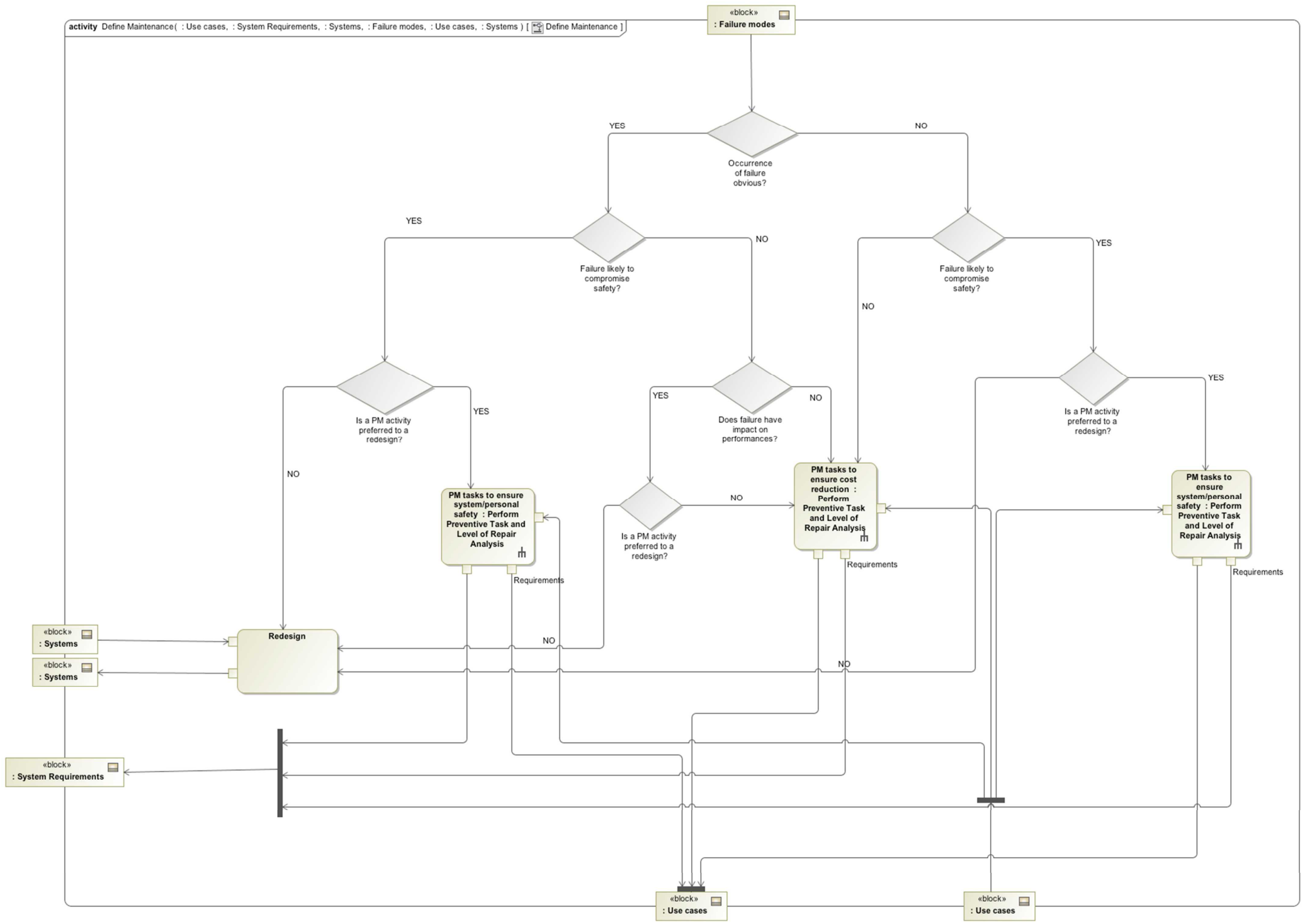

Figure 33: Define maintenance activities description.

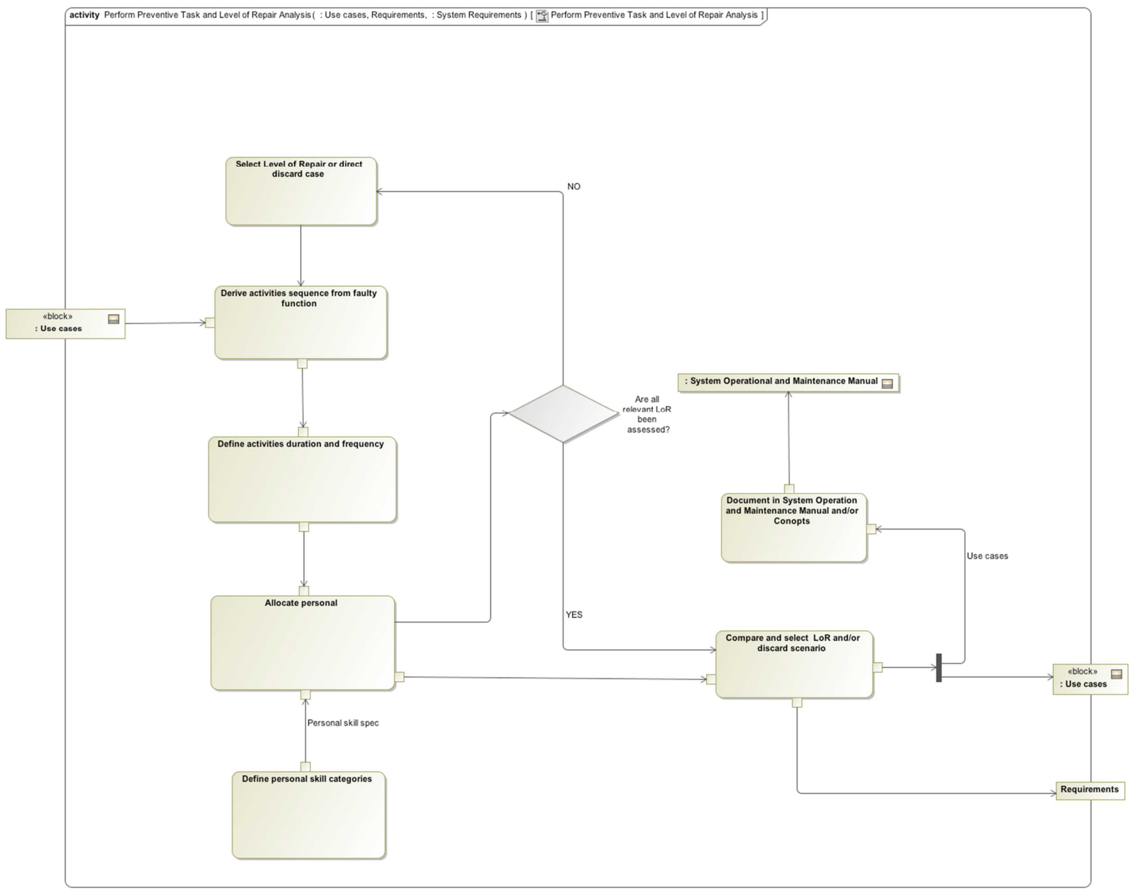

Figure 34: Perform MTA and LoRA activities description.

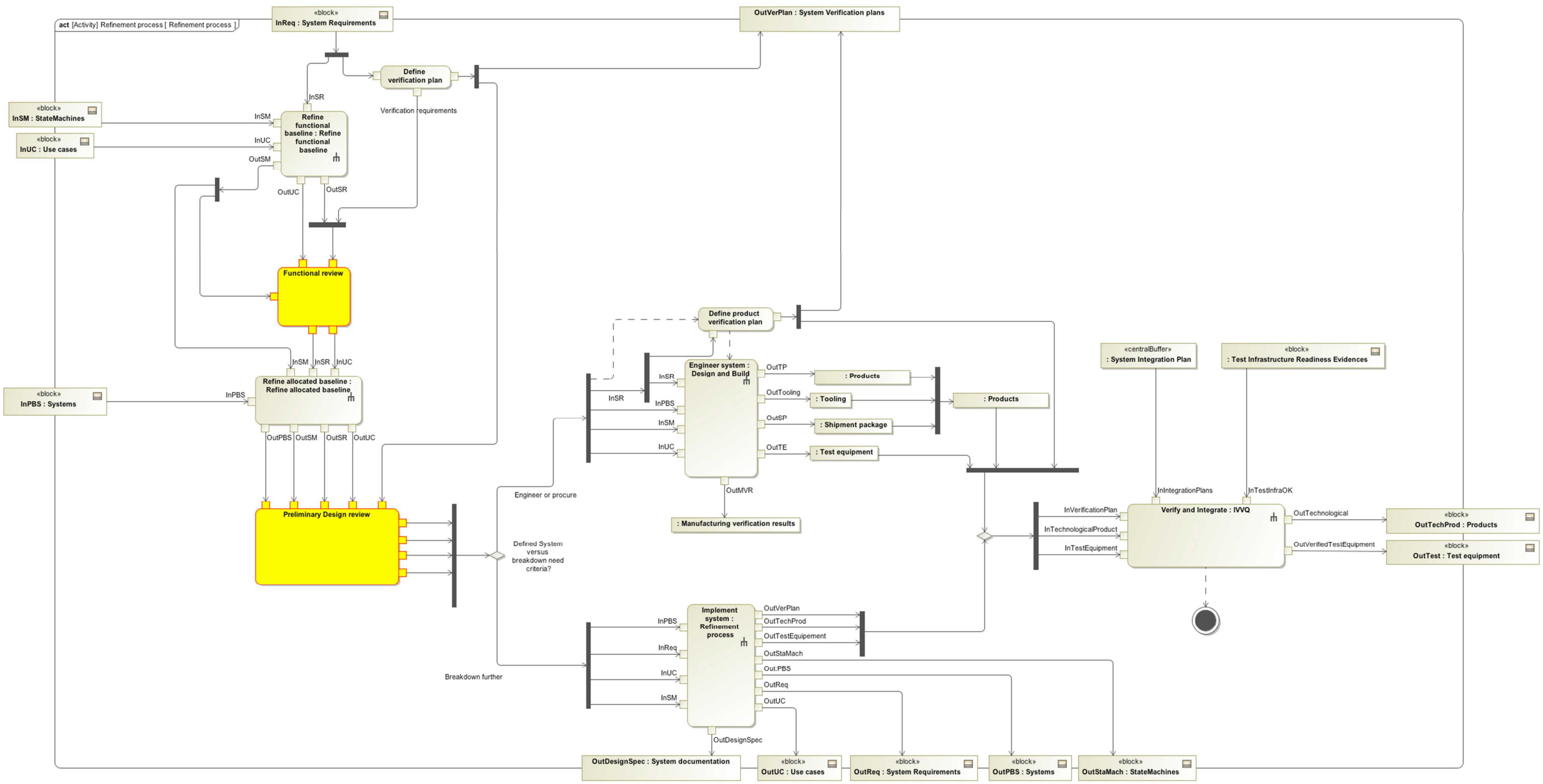

Figure 35: Refinement Process activities description.

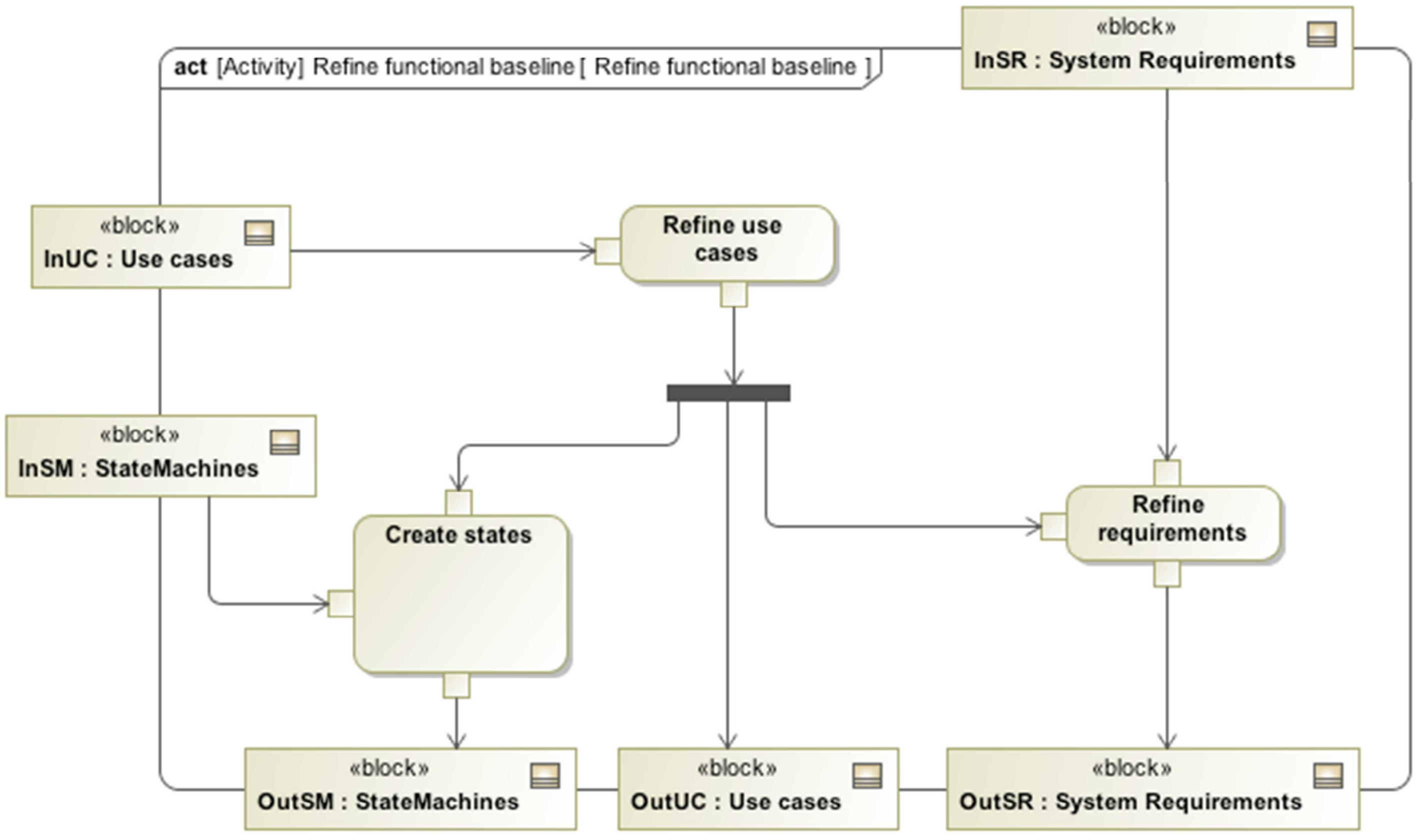

Figure 36: Refine functional baseline activities description.

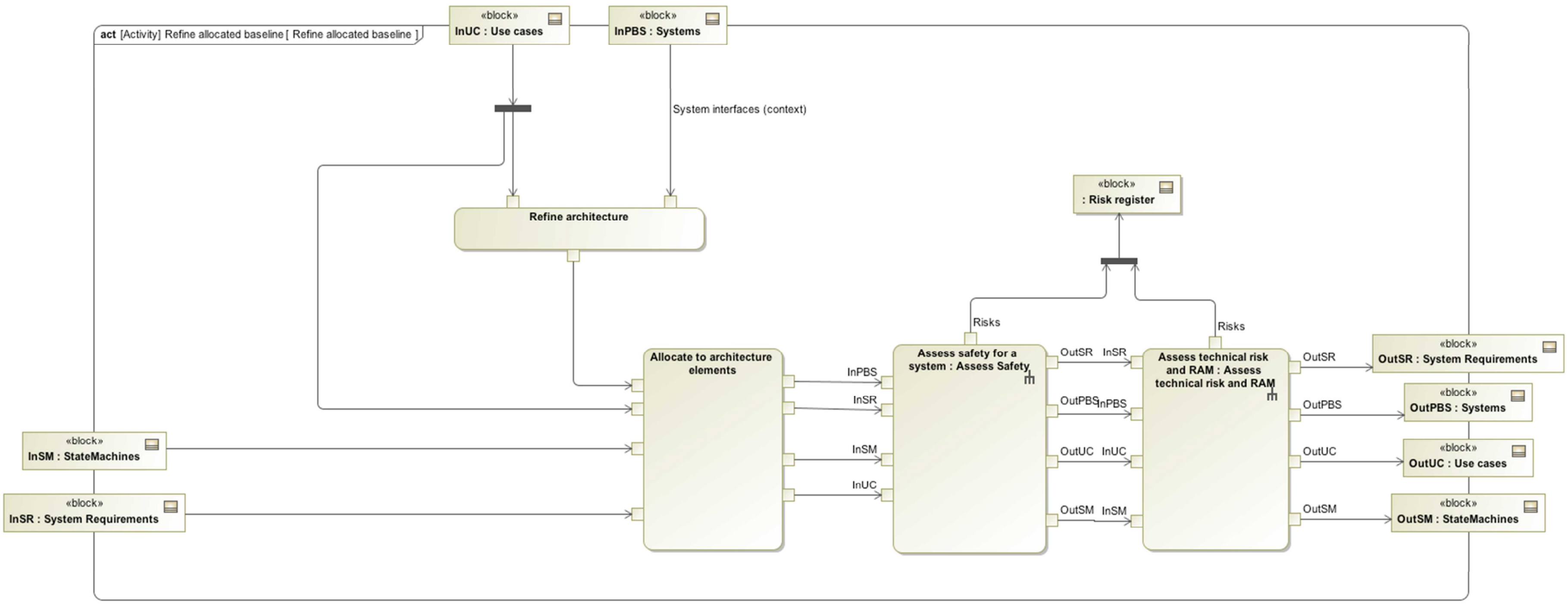

Figure 37: Refine allocated baseline activities description.

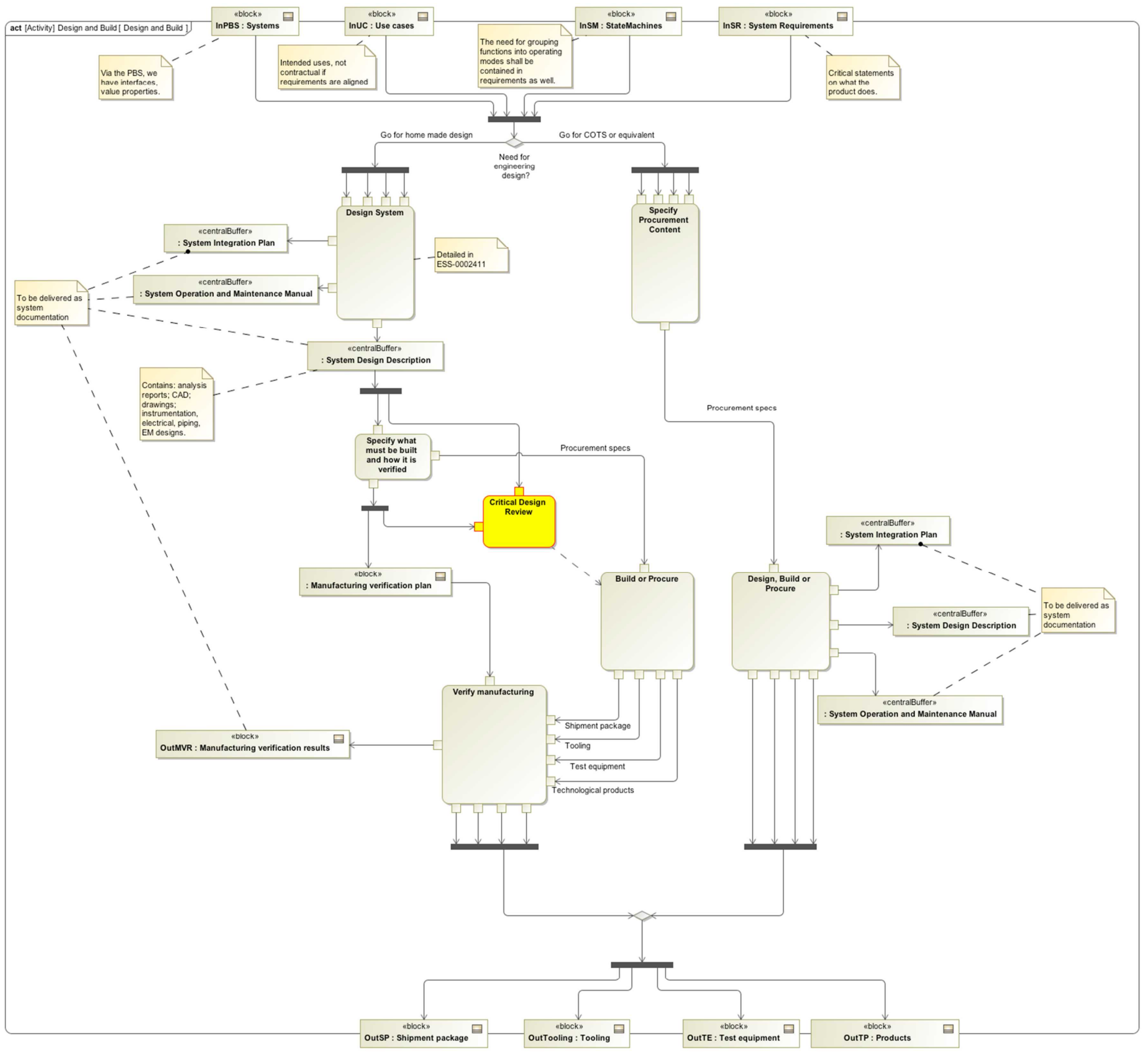

Figure 38: Design and Build activities description.

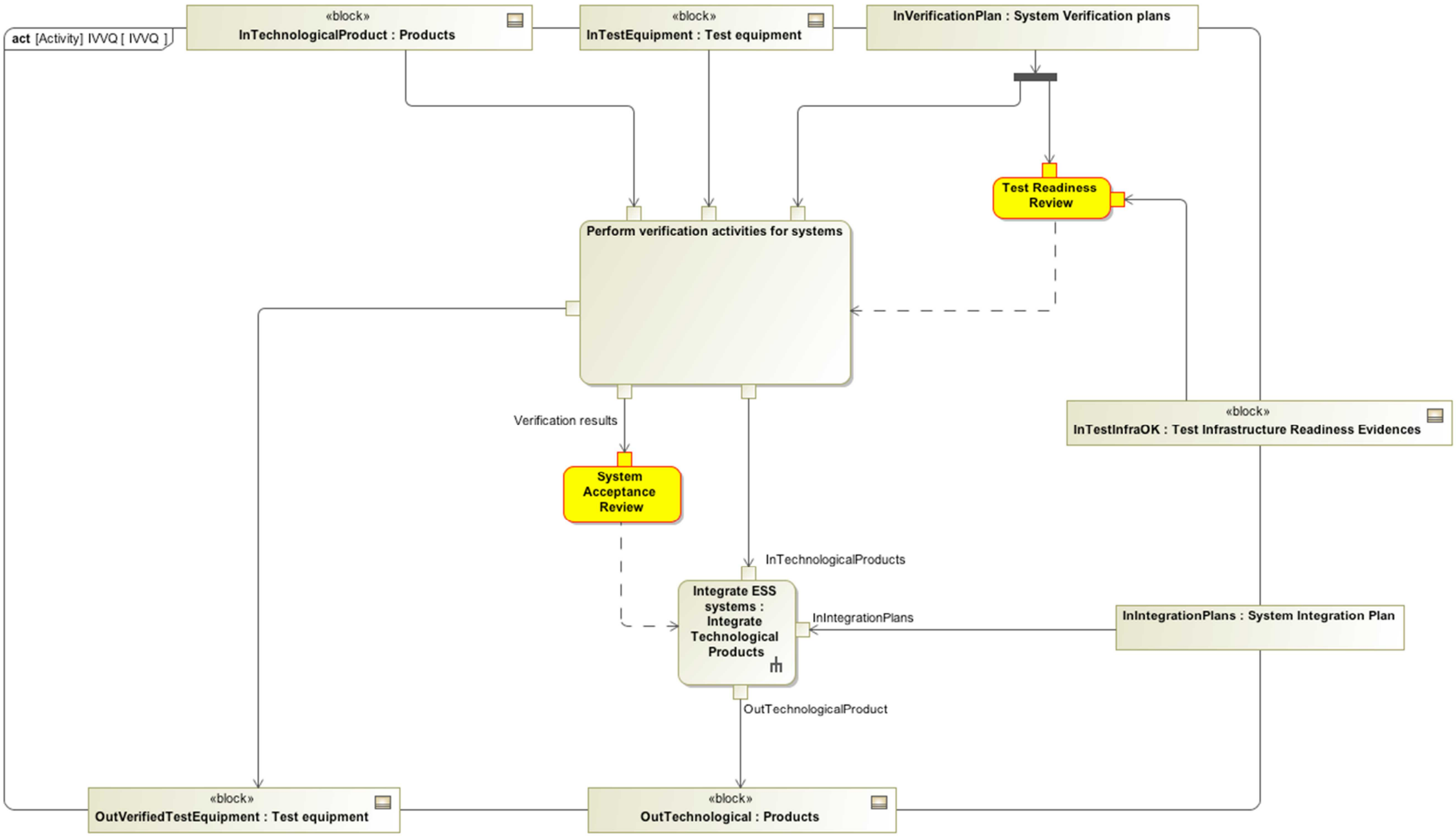

Figure 39: IVVQ activities description.

Description

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Date	17 Feb 2012