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National foreword

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Luft- und Raumfahrt - Programm-Management - Leitfaden für das Management von Systemtechnik

This European Standard was approved by CEN on 11 November 2014.

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European foreword

This document (EN 9277:2015) has been prepared by the Aerospace and Defence Industries Association of Europe - Standardization (ASD-STAN).

After enquiries and votes carried out in accordance with the rules of this Association, this Standard has received the approval of the National Associations and the Official Services of the member countries of ASD, prior to its presentation to CEN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by March 2016, and conflicting national standards shall be withdrawn at the latest by March 2016.

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Introduction

This document aims to address the current challenges of the programmes that are:

— the multi projects approach,

— the multi-disciplinary approach,

— new methods of acquisition,

— the increasing complexity of systems to be acquired,

— the evolving aspects of the system and its incremental development,

— the complexity of the management of projects in terms of organization,

— the evolution of the industrial sectors.

In this document the system considered comprises a target system and elements (products, processes, etc.) needed for developing, producing and using it, in other words a range of end products and products supporting the lifecycle of the target system.

The case where the system is only an element of the service provided (no system is acquired, service only) is not adressed in this document.

Systems Engineering (SE) cover a set of activities which, based on a perceived operational need and via an organized approach, aims to:

— describe this need in technical terms,

— gradually transform it into a system solution,

— at each stage, demonstrate that this system is compliant with the need.

Systems Engineering:

— considers the system as a whole and in all situations of its lifecycle,

— provides a framework for combining various technical disciplines (electronics, data processing, mechanics, ergonomics, etc.) and some enterprise functions (design, production, logistics, tests, etc.) without necessarily intervening in these disciplines and functions,

— aims for the overall optimization of the solution in a field of constraints (costs, schedule, performance, strategy, etc.) established by the Programme management,

— guarantees consistency between all components of the solution (functional and physical interfaces).

In this document, the organisational dimension is essential to reach the overall objectives. The complexity of the system and the complexity of the organisation are correlate (the more complex the system is, the more control of the organisation is necessary).

Its position with respect to other normative documents handling Systems Engineering (ISO/IEC 15288, EIA 632,IEEE 1220, EN 9200) is represented in Annex A. This document falls within the scope of EN 9200 and ISO/IEC 15288, focusing on aspects linked to the management of the technical activities of SE with a higher level of detail. It relies partly on the SE process described in ISO/IEC

15288:2008 and if necessary with addition from EIA 632, adding the project phasing and scheduling aspect. It overlaps little with IEEE 1220 as such, which concentrates primarily on SE technical activities.

1 Scope

Based on the following considerations:

- reminder of Systems Engineering and its scope of application,
- positioning of SE management in Programme Management and in relation to Systems Engineering technical activities,
- identification of interfaces between SE management and the other disciplines linked to Programme Management,

the purpose of this standard is:

- to help the acquirer and the Organization to establish management requirements for SE activities,
- to help the supplier to construct the elements of the management plan (explain how to reply in particular to the management requirements).

This standard applies to the various levels of the product tree for the products that can be considered as systems:

- in the general case of an supplier which, with the help of one or more suppliers, develops a system on behalf of an acquirer,
- in the case of an integrated team (sharing of SE roles, responsibilities and risks).

NOTE ISO/IEC/IEEE 24765:2010 integrated team should include organisation discipline and functions which have a stake in the success of the work products.

This standard constitutes a guide illustrating the requirements and possible responses for SE management. It can be used as a check-list which should be adapted or completed according to the specific context of each project.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 9200, *General recommendation for the project management specification*

EN 12973, *Value management*

EN ISO 9000:2005, *Quality management systems — Fundamentals and vocabulary (ISO 9000)*

ISO 9220, *Metallic coatings — Measurement of coating thickness — Scanning electron microscope method*

EN ISO 9241-210:2011, *Ergonomics of human-system interaction — Part 210: Human-centred design for interactive systems (ISO 9241)*

ISO/IEC 15288:2008, *Systems and software engineering — Systems life cycle processes*

ISO/IEC/IEEE 24765:2010, *Systems and software engineering — Vocabulary*

EIA 632:2003, *Processes for Engineering a System* [1)]

IEEE 1220:2005, *Standard for Application and Management of the Systems Engineering Process* [2)]

3 Terms and definitions

The following referenced documents are essential for the application of this document. For dated references, only the written issue applies.

For the purposes of this document, the following terms and definitions apply.

ISO/IEC/IEEE 24765:2010 Systems and software engineering vocabulary should be used for the definition. In addition, the following standards should be used for definition as ordered:

— ISO/IEC 15288:2008, *Systems and software engineering — Systems life cycle processes*

— EN ISO 9241-210:2011, *Ergonomics of human-system interaction — Part 210: Human-centred design for interactive systems*

— EIA 632:2003, *Processes for Engineering a System*

— IEEE 1220:2005, *Standard for Application and Management of the Systems Engineering Process*

— EN ISO 9000:2005, *Quality management systems — Fundamentals and vocabulary*

3.1
complexity
characteristic of a process linked to the number and diversity of participants, components and technologies, involved in the design and production of products and the supporting logistics

3.2
iterativity
characteristic of a process which is repeated several times in full or in part, with a search for convergence towards a product meeting the expressed need

3.3
recursivity
owing to the system breakdown into sub-systems, repetition of the SE process at various breakdown levels with strong interaction between the levels

3.4
system
set of complex hardware, software, personnel and operational processes, organized so as to satisfy the needs and fulfil the expected services, in a given environment

3.5
systems engineering
interdisciplinary approach governing the total technical and managerial effort required to transform a set of customer needs, expectations, and constraints into a solution and to support that solution throughout its life

Note 1 to entry: Includes the definition of technical performance measures; the integration of engineering specialties toward the establishment of architecture; and the definition of supporting lifecycle processes that balance cost, performance, and schedule objectives.

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1) EIA National (US) Electronic Industries Association http://www.eia.org/

2) IEEE International Institute of Electrical and Electronical Engineers http://www.ieee.org/

3.6
scalability
the ability to change the component configuration of a system to fit desired application context

Note 1 to entry: Component configuration changes may be obtained by deployment of items or by setting configuration parameters of each item.

3.7
upgradability
potential ability of a system, subsystem or component to respond to changes in operational requirements and anticipated or foreseeable technical changes without affecting the basis of its structure

Source: ISO 9220.

4 Symbols and abbreviations

For the purpose of this document, the abbreviations used are clarified below:

- CAD : Computer Assisted Design
- FS : Functional Specifications
- ILS : Integrated Logistics Support
- MP : Management Plan
- MS : Management Specification
- (N)TS : (Need) Technical Specification
- PDCA : Plan/Do/Check/Act
- PTS : Product Technical Specification
- SE : Systems Engineering
- TS : Technical Specification

5 Positioning of Systems Engineering and SE management within a project

5.1 The need for Systems Engineering Management

Within the business activities, two different and complementary visions co exist. SE vision highlights the following main objectives:

a) The management of SE activities giving assurance that all SE activities are identified, planed, monitored and controlled:

  - before launch of the project through the identification of the technical activities to perform during the project to satisfy needs of the system development and project constraints (costs, schedule, performance),

- during the project through the identification of the engineering tasks, the relevant resources including human resources, the appointment of the main responsibles, the reporting needed to monitor and control the progress of the engineering,

- along the project maintain the compliance of the system design and definition with the requirements.

b) Contribution of the Systems Engineering to the Programme:

- converting a set of needs into a system meeting the set of needs, through a systematic approach contributing towards an integrated design of the product and associated manufacturing, testing and support processes,

- from a technical point of view, managing and optimizing the system performance in accordance with the Programme objectives and constraints,

- enable to deploy a gradual demonstration that this system meets the set of needs,
- identifying the system technical risks and conducting risk mitigation actions, and contributing to the overall risk management process.

A strong coordination and integration is essential, justifying the creation of formalized specific SE management, for example through an SE specification and MP.

Indeed, some main characteristics differentiate the SE with respect to conventional engineering activities and justify the need for specific SE management:

- imprecise requirements, which are refined during development, supplemented by assumptions;
- complexity of the environment, interacting closely with the system (Man Machine Interface, field of operation, etc.);
- complexity linked to the number and diversity of stakeholders, the number of different technologies, the products themselves and the supporting logistics (system dedicated to multi acquirers on multi markets);
- iterativity; recursivity of project processes;
- scalability of the system;
- upgradability of the systems, sub-systems and components.

Systems Engineering involves both the Acquirer and the Supplier(s) of the Organization and comprises the various technical processes which iteratively and exhaustively contribute to ensuring that the solution meets the need throughout the lifecycle of the system.

See Figure 1 — Systems Engineering positioning in relation to Programme Management.

SE management is therefore not restricted to management of the Organization's SE technical activities, but must also provide the link with the higher and lower level SE activities (Organization's acquirers and suppliers).

In this context, cooperative Acquirer/Organization/Supplier working methods will be encouraged in order to improve data exchanges, partner reactivity and convergence towards common requirements and solutions (for example: networking, shared data environment, etc.).

The large number of stakeholders (owing to the numerous disciplines involved and the Acquirer/Organization/Supplier tree) similarly requires specific SE management to ensure the consistency of the work done, the consistency of the data and of technical data flow.

Consequently, SE management requires the use of specific methods, tools and skills.

5.2 Relation between SE management and Programme Management

Given the need for Systems Engineering Management, the overall SE process can be split into 2 types of activities:

- SE management activities which are included in Programme Management and which comprise planning, management and control of SE technical activities,
- the technical activities themselves, linked to the technical processes (Acquirer needs analysis, design, verification, validation, etc.) applied to the system.

See Figure 1 — Systems Engineering positioning in relation to Programme Management.

The main role of SE management within Programme Management is to ensure system performance in conformity with the expressed need and to control the technical risks involved in the development. Besides, SE management contribute to the Programme Management for all technical aspects of the system through the whole lifecycle. SE management therefore reinforces the technical viewpoint within the Programme Management.

The cost and schedule parameters, which are the responsibility of Programme Management are taken into account in SE management as input constraints in the search for optimum performance: SE management must measure all the resulting consequences in terms of technical choice and associated risks for the project and help Programme Management to define the performance/cost/schedule trade-off in cooperation with all the stakeholders.

5.3 Positioning of SE in relation to Programme Management

For a given Organization (level N), Figure 1 presents the positioning of Systems Engineering in relation to Programme Management within a generic Acquirer Supplier relationship, as well as the central positioning of SE management between Programme Management and technical activities.

This figure applies to any organization, from the end user up to the furthest downstream suppliers. In this figure, the notion of acquirer is to be taken in the broadest sense. It includes all the stakeholders outside the Organization expressing needs to it (contracting organizations, certification Authorities, end-user, etc.).

All the SE, technical and management activities together, are organized according to a reference process recalled in Clause 6 and described in Annex D. The relations between the SE technical and management activities are defined in Clause 7.

SE management uses the elements of the management plan related to SE in reply to all the management requirements specific to SE expressed on the one hand in the Acquirer's management specification and on the other hand internally by the Organization (Clause 8).

SE management also interfaces with all the other components of Programme Management such as Integrated Logistics Support, risks and RAMS management. These interfaces are explained in Clause 9.

In the Figure 1 — Systems Engineering positioning in relation to Programme Management, the solid line circles inside the Acquirer, Organization and Supplier entities represent the activities carried out by these entities (the what) without anticipating the organization put in place to carry them out (the who) which can fluctuate from one Organization to another and one project to another Figure 1 — Systems Engineering positioning in relation to Programme Management.

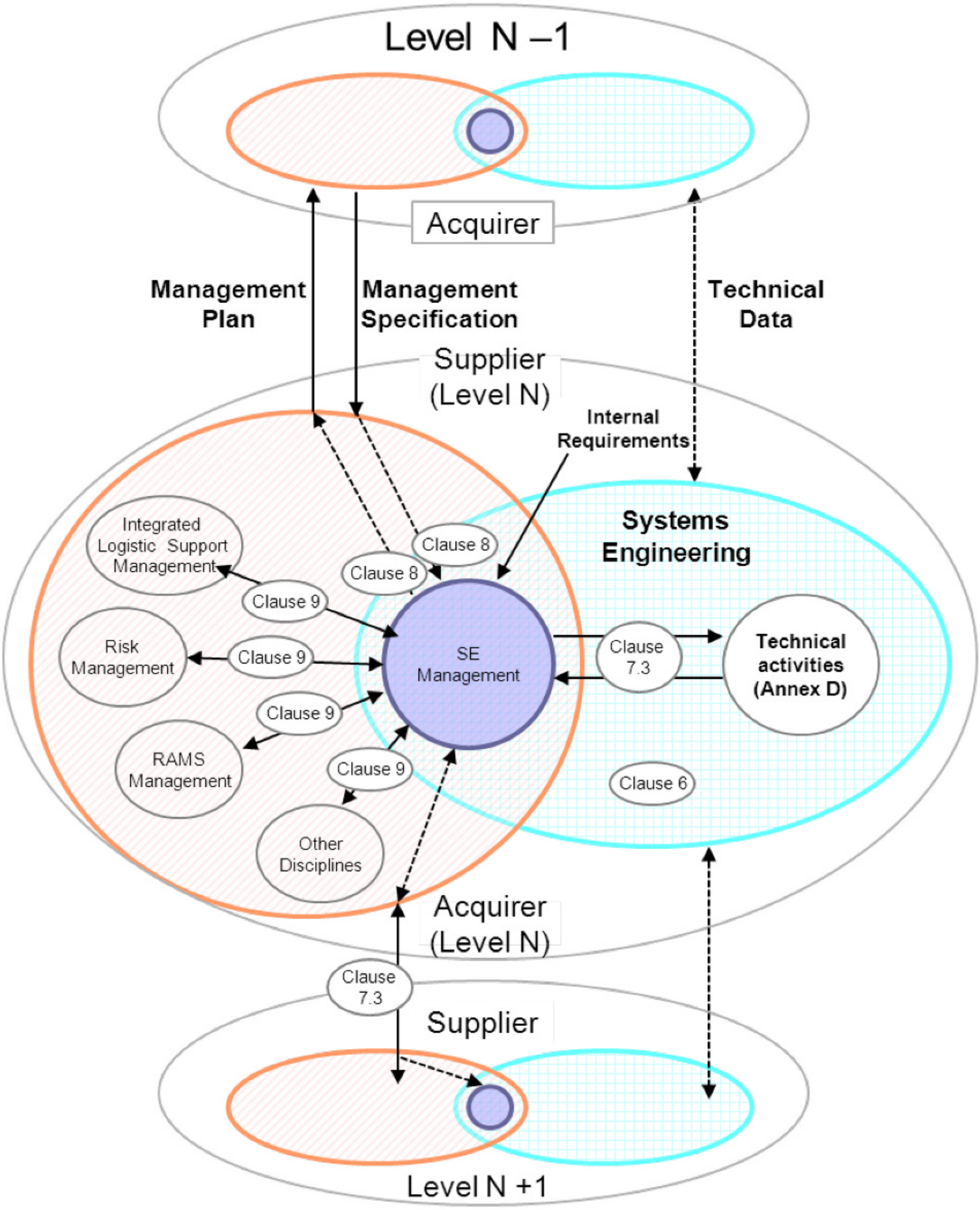

Figure 1 — Systems Engineering positioning in relation to Programme Management

6 Systems Engineering process

6.1 Reference process

The basic SE process is described in EIA 632 through static relations (no phase sequencing) between activities, without specifying the Actors in this process. The approach of this standard is to supplement this view by handling the time aspects of the SE process within a project phasing and scheduling approach with responsibilities sharing in the Acquirer Supplier relationship, as envisioned by EN 9200.

Thus, it was proved necessary to combine these two visions in order to obtain a reference process for the rest of the document.

The description of the SE process activities is detailed in Annex D. Regular reference to this annex is strongly recommended for a clear understanding of the management requirements in Clause 8.

6.2 Technical activities

The SE process comprises the following technical activities:

- expression of the Acquirer's need;
- system design incorporating:
  - analysis by the Organization of this need and the system requirements definition,
  - definition of the system solution: structuring, requirements allocation and components specification.
- modelling/simulation (performance, etc.);
- technical assessment comprising:
  - requirements validation,
  - system analysis,
  - system verification,
  - system validation.

The content, players and inputs/outputs of these activities are described in Annex D.

NOTE Due to its growing role in the development of complex systems (for example mock-ups and virtual products), modelling/simulation is here considered to be an activity in its own right, going beyond the simple framework of systems analysis.

The SE process is also involved in the following technical activities:

- acquisition of components from the Suppliers of the Organization (or in-house),
- integration of these components into the system,
- development of the supporting logistics,
- transition to use placing of the final system at to the Acquirer's use (installation and commissioning in the Acquirer's environment).

The SE activities are carried out iteratively for each level of the product-tree which can be considered as a system, refining the requirements and the solutions at each iteration. Moreover, these activities are repeated recursively from level to level of the product-tree.

These activities comprise the flow down of the needs, the search for and consolidation of solutions. The chosen solutions are gradually detailed and then implemented (the implementation activities are not part of SE).

All these activities contribute to controlling the performance of the system, in other words, obtaining, optimizing, checking and validating this performance.

6.3 Interactions between technical activities

Figure 2 represents the interactions, flows and looping (non-chronological) between the technical activities in the SE process. The activities are positioned in it according to the field of responsibility of each player (Acquirer, Organization, Supplier). The scale of shading differentiates the SE activities from those in which the SE process is simply involved. The “supporting logistics development” activity is not represented because showing its interactions with the other activities would degrade the overall legibility without really adding any significant value.

The direct process activities and flows, ranging from expression of need to transition to use, are represented differently (bold simple arrows) from the loop flows used to check that each step has been achieved correctly and iterate if necessary (simple arrows). The specific interactions between system analysis and the other activities are represented in a particular way (dotted two-way arrows).

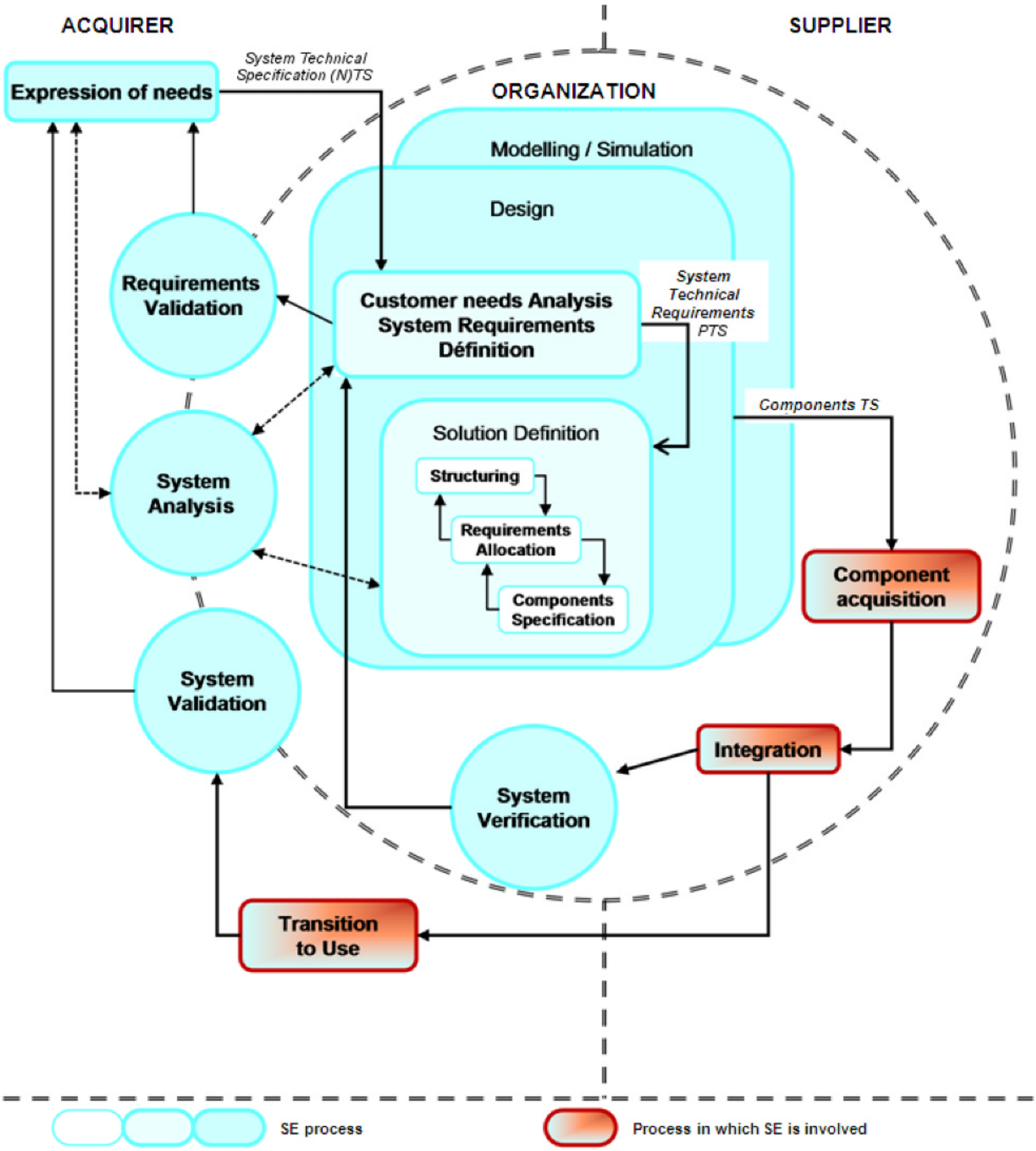

Figure 2 — Interactions between the SE process technical activities

6.4 Activities specific to Systems Engineering management

This standard focuses on the management activities designed to control the specific aspects of SE described in 5.1, without dealing with the more conventional aspects linked to Programme Management (contract, breakdown of tasks, planning, etc.). See Table 1.

Table 1

Objective criteria	Activities
To guarantee the compliance of system design and definition with the requirements	Ensure the consistency and exhaustiveness of the requirement allocations during the breakdown into sub-systems. Ensure the consistency and exhaustiveness of the proposed sub-system solutions when reconstituting the system. Ensure the compatibility of the functional and physical interfaces both within the system and with the world outside the system. Specify and analyse the tests and provings concerning the system or its components.
To ensure system performance convergence	Iteratively seek consistency between the performance of the system and the performance of the sub-systems. Allocate or re-allocate performance values, taking account of the technical risks and design margins, by implementing the following techniques: — analysis of robustness, sensitiveness, reliability, limit tests; — use of models and simulation tools. Take advantage of the new properties of the system observed during development (notion of emerging properties). NOTE Given the characteristics of a system, the system optimum is rarely the sum of the optima of its sub-systems. Optimization is therefore carried out overall: — on the complete system rather than separately for each component of the system, — on a given component, between several performance parameters.
To ensure control of the SE process	Manage and coordinate the SE technical activities as defined in section 6.2. Manage the many independent technical data originating from all the technical disciplines involved in the project: — document, validate and regularly distribute technical data concerning the system (technical decisions, system design data, etc.); — implement processes and tools to ensure data traceability and consistency (in addition to traceability at document level); — organize data flows between the system components and ensure exchange compatibility (formats and synchronization); — manage changes and harmonize configuration management rules for the various areas of expertise (system and sub-systems configuration, models, CAD tools, etc.);
To reinforce the technical viewpoint of Programme Management	Ensure that the technical risks are identified and analysed and that risk mitigation actions are defined; Ensure that criteria have been established and indicators are in place to assess whether the engineering efforts and the system performed will be able to meet the requirements.

The above activities are conducted by the Organization and by the Acquirer/Organization/Supplier network (recursivity), within the context of overall coordination provided by Programme Management.

The breakdown of these management activities according to each of the SE technical activities is illustrated in Clause 8 in the form of examples of requirements and elements of the MP.

6.5 Systems Engineering management, phasing and scheduling and recursivity

Figure 3 represents the SE process activities organized according to a “project phasing and scheduling” vision that is both generic and macroscopic. This vision enables management to identify all the tasks and apply a sequencing logic to them (e.g.: acquisition of components is initiated when the system design is considered as mature enough).

In order to control the iterative nature of the SE process, this is the SE management which determines the interactions between activity in terms of data flow and sequencing and which dynamically determines the possible iterations and the stopping criteria.

This figure does not show any possible reactivation of closed activities (e.g.: an unsatisfactory validation may leads to reactivate the “expression of need” task. Another example: a change in the need during the course of the project may leads to reactivate a process cycle).

In addition to the “phasing and scheduling vision”, the notion of recursivity between the different system breakdown levels is illustrated in Figure 4. In this Figure, the SE process is repeated overall at component acquisition level, requiring complex interactions between the various management levels and technical activities.

In order to control the recursive nature of the SE process, the feedback of results with respect to the requirements and between the levels of the product-tree are determined dynamically by SE management.

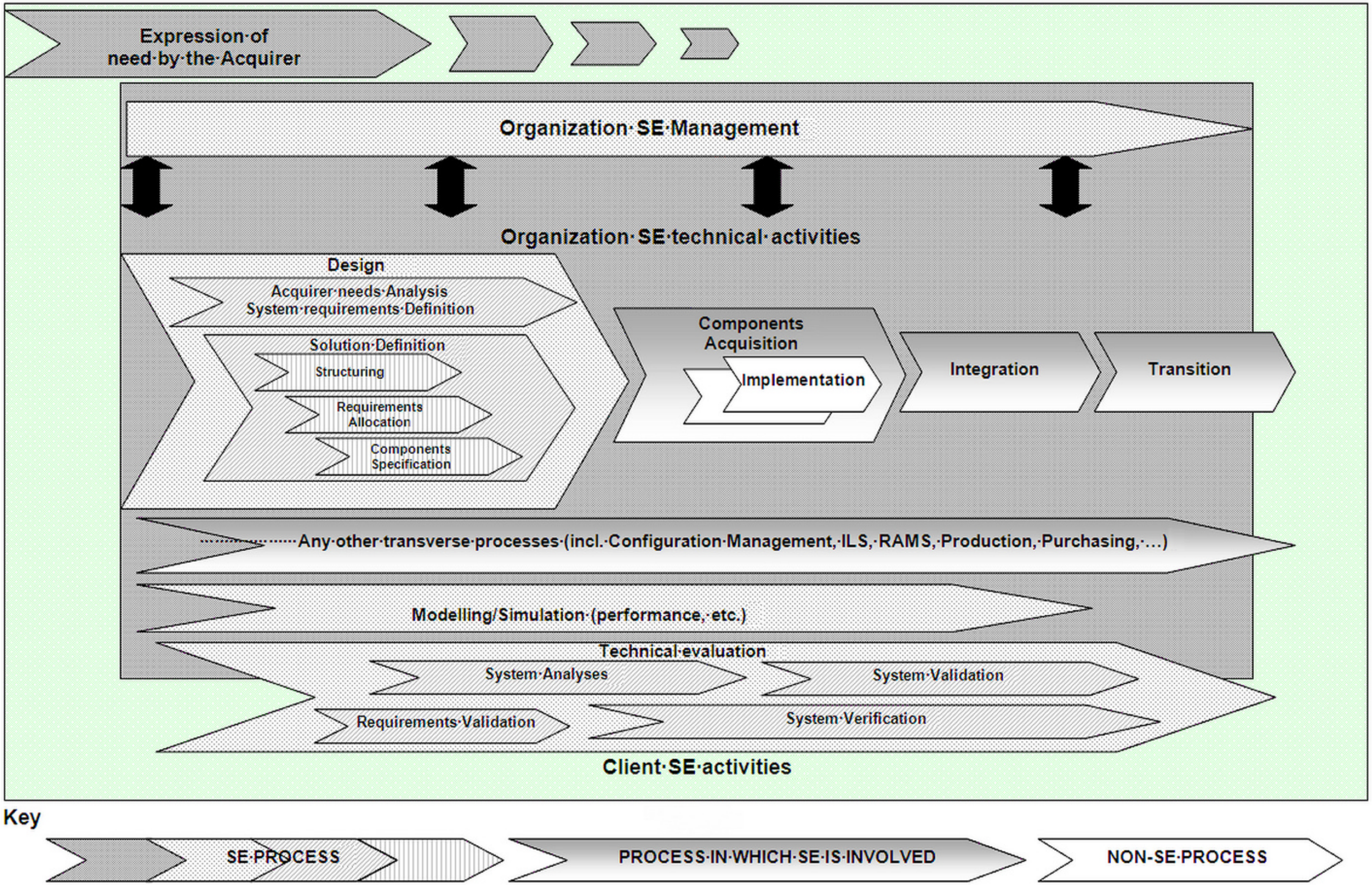

Figure 3 — "SE Process phasing and scheduling" vision

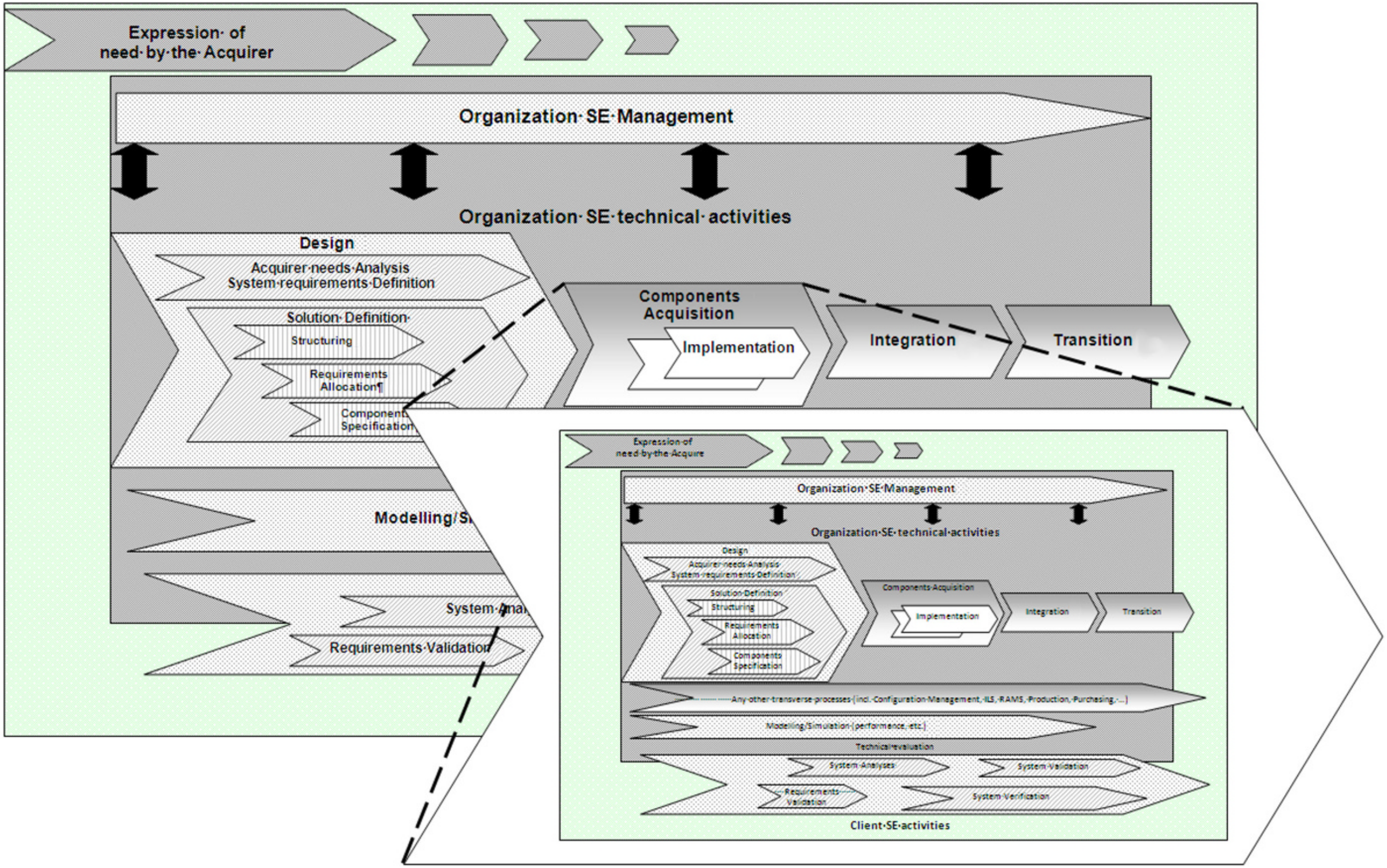

Figure 4 — Recursivity of SE management and technical activities

7 Principle for defining requirements and elements of the management plan

7.1 Approach

The approach chosen in this standard to define the requirements and the elements of the Management Plan concerning the SE consists:

- firstly, in specifying the role of the Management Specification (MS) and Management Plan (MP), documents exchanged at project level between the Acquirer and the Organization, for controlling SE at Organization level;
- secondly, in identifying the interactions between on the one hand the management activities and on the other hand the technical objects and activities which are typically observed during running of a project. These interactions are then analysed and traced using tables which are based on the PDCA management model and focused on the characteristic aspects of the SE;
- finally, concatenation of the elements of these tables, after application to the Acquirer/Organization relationship, allows drafting of SE-related elements of the MS and MP documents.

7.2 Control of Systems Engineering technical objects and activities

The sections dedicated to SE in the project MS and MP (or the MS and MP documents specific to the SE when they are differentiated) are the management baseline applicable throughout the project to the relations between the SE management of the Acquirer, the Organization and the Supplier.

The purpose of applying this baseline is to ensure control by the Organization:

- of the flow of technical objects that can be directly exchanged between the Organization and Acquirer SE technical activities,
- of the Organization's SE technical activities,
- of the flow of technical objects that can be directly exchanged between the Organization and the Suppliers SE technical activities.

This mechanism is reproduced at each level on the Acquirer/Organization/Supplier tree.

Figure 5 represents the flow of MS requirements and of MP elements and the flow of technical data as part of a Acquirer/Organization/Supplier tree. The “table” symbol represents the analysis table mentioned in 7.1 and described in 7.3.

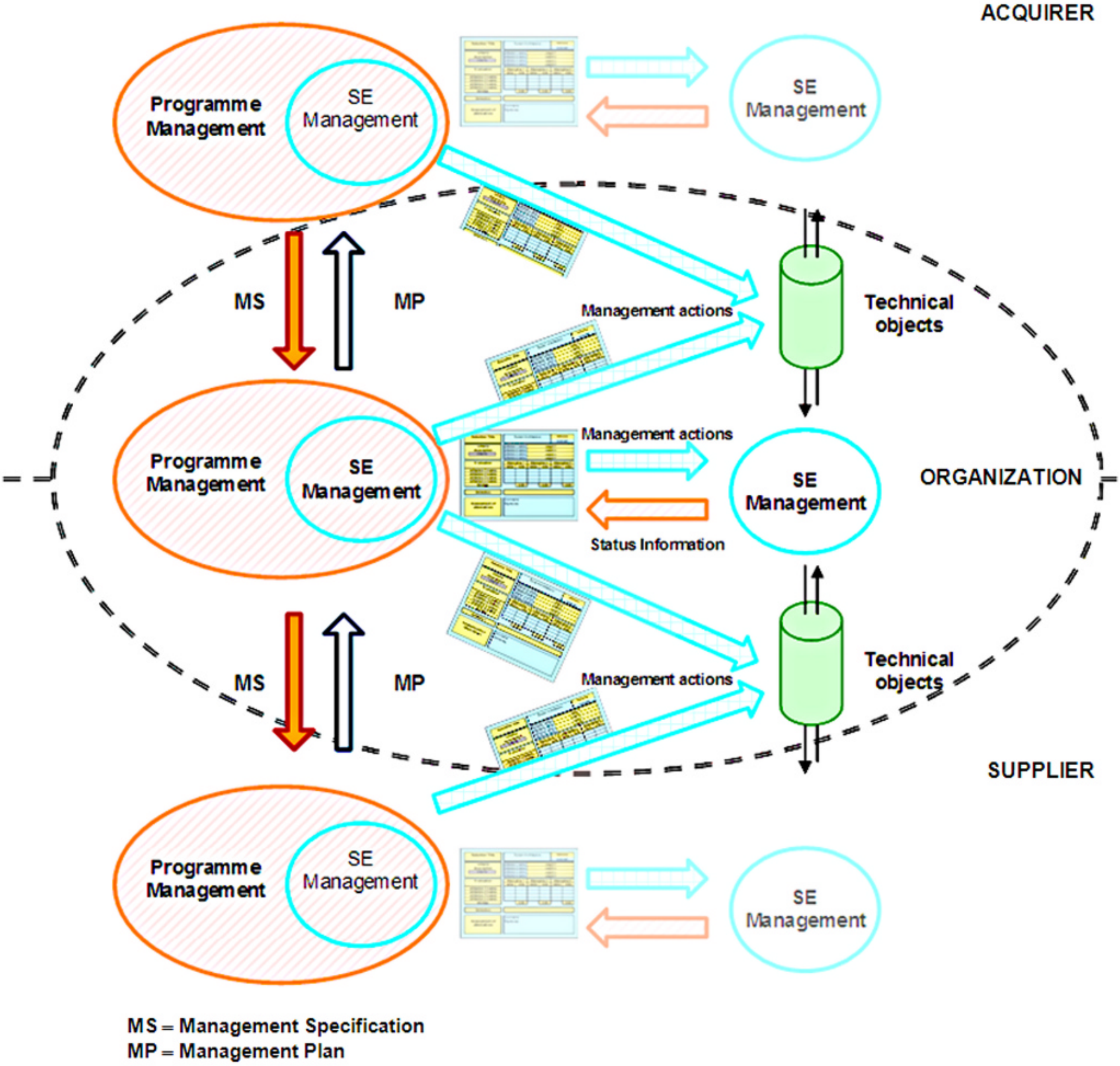

Figure 5 — Interactions between SE management artefacts (MS, MP, ...) and technical objects across the design layers

7.3 Interactions between management activities and technical objects and activities

The SE management activities are structured according to the "PDCA" (Plan/Do/Check/Act) cycle model. Applying this model to control of SE technical objects and activities is a mean of guaranteeing good control and permanent optimization of these objects and activities.

This model has been refined to allow a more precise identification of the management actions. For example, the overall "Plan" action covers the following basic actions: identify, describe, select, etc.

Each technical activity is characterized by a set of objects representative of it: input and output data and products, resources and organization.

The interactions between the technical and management activities are shown in Figure 6 in the form of management actions directed towards technical activities and concerning the objects of this activity. In response, the technical activity gives status information about the input/output data and products, the resources used and the organization put in place.

The PDCA cycle runs continuously throughout the project. This cycle sets the timing of the interactions between the technical and management activities, in order to control the iterative aspect of SE and ensure convergence.

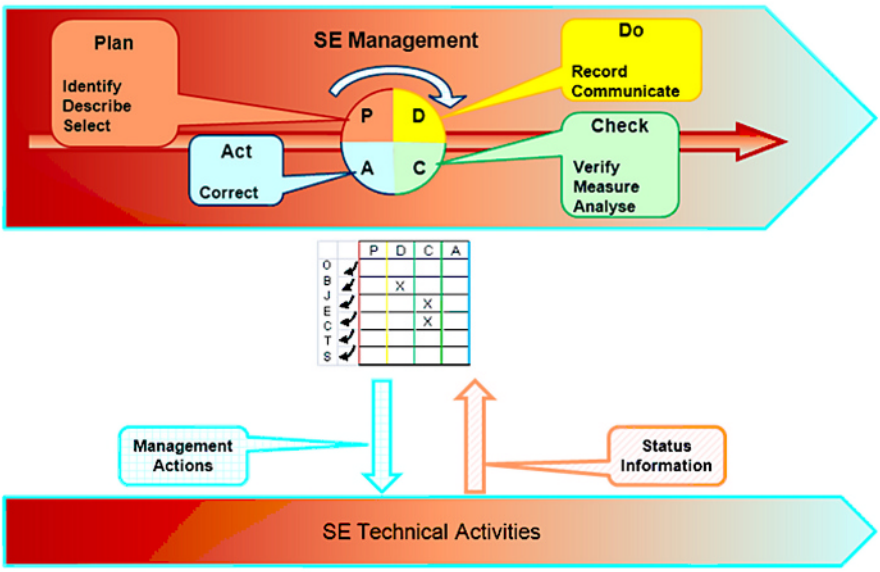

Figure 6 — Interactions between the technical activities and SE management

7.4 Drafting of requirements and elements of the Systems Engineering management plan

The interaction model presented above has been used to define a structured method for identifying management requirements and elements of the MP. This method is described in Annex B of this standard.

Therefore, to draft SE Management requirements, the Acquirer could use the following steps:

a) Apply the method defined in Annex B, on the basis of the generic SE process presented in 6.2, adapting it to the given project.

b) Refine the requirements with the Organization in order to determine the exact need.

When drafting the requirements, care will be taken to formulate them in terms of management actions.

In drafting the elements of the MP, in particular replying to these management requirements, the Organization may follow a similar method applied on the basis of its own SE process and its own organization.

NOTE The elements of the management plan may be covered by a specific SE plan separate from the overall management plan (see outline in EN 9200).

This method is recursive and can be broken down in the Acquirer Supplier relationship.

8 Examples of management requirements and elements of the management plan concerning Systems Engineering

NOTE This paragraph is an application of the project processes of ISO/IEC 15288:2008.

8.1 General

For each activity of SE described in Annex D, this Clause on the one hand gives an illustrative example of a SE management specification in the form of a list of management requirements from the Acquirer to the Organization (which is its supplier) and on the other hand gives elements of the MP from the Organization to its Acquirer in order to comply with these requirements.

The examples are chosen from among the usual good practices, with no search for exhaustiveness.

Significance of technical and project processes activities depends on system lifecycle phase, the system-of-interest and its associated lifetime, the requirement and operational environment stability, and the technical solution maturity as shown in the Figure 7.

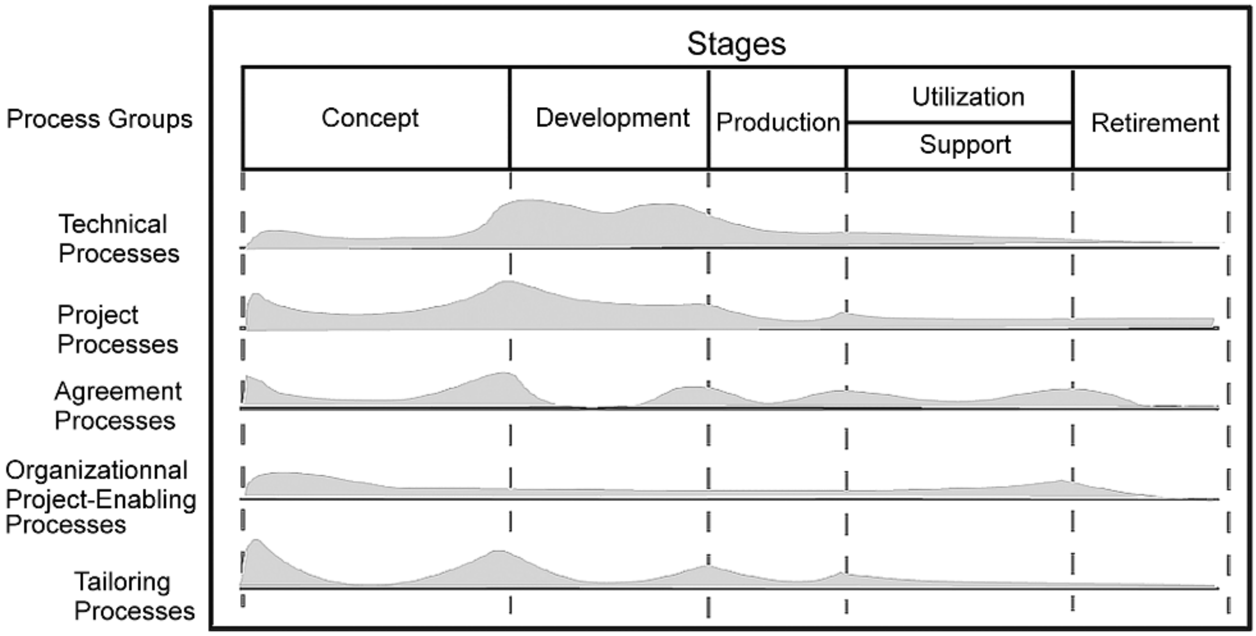

Figure 7 — System Engineering Level of Effort across Life-Cycle Stages
[SOURCE: INCOSE Systems Engineering Handbook]

8.2 General Systems Engineering Management requirements

8.2.1 Management requirements

8.2.1.1 The Organization in charge of developing a system will be able to demonstrate that a SE process has been defined then implemented and that it comprises two main sub-processes, the interactions of which have been identified:

— a process for implementing the SE technical activities,

— a process for managing these technical activities.

8.2.1.2 The sub-process for managing the SE technical activities will comply with the requirements expressed by the Acquirer in the Management Specification using the method defined in this standard.

8.2.1.3 The SE management requirements will be flown down to the Suppliers of the Organization in charge of developing the sub-systems, for example in the MS intended to the Suppliers.

8.2.2 Elements of the management plan

8.2.2.1 The SE technical and management activities follow the process described in this standard.

8.2.2.2 To flow down the SE management requirements to the Suppliers, the method defined in this standard is used.

8.3 Expression of need by the Acquirer

8.3.1 Management requirements

As this process is primarily performed by the Acquirer, the management requirements cannot here be expressed as such because they concern the Acquirer itself for its own SE management activity. Here we simply present a few recommendations for use by the Acquirer to ensure the quality of its expression of need. Owing to the recursivity of the process, these recommendations also apply to the Organization for the "solution definition" activity, as part of the flowdown of requirements for Suppliers (see 8.6).

8.3.2 Recommendations

8.3.2.1 In order to acquire a clear knowledge of its own need, it is recommended that the Acquirer conduct technical/economic/operational studies, for example: functional analysis to identify the service functions, value analysis to select these functions and optimize the required performance levels, operational simulations, and so on.

8.3.2.2 In the expression of need intended for the Organization, the Acquirer will indicate the operational scenarios, the operating situations, etc. To do this, whenever possible, it will use simulation to represent the needs in order to ensure that there is mutual understanding of the needs expressed.

NOTE These means could also be used to validate the solution concepts.

8.4 Acquirer needs Analysis and System requirements definition

8.4.1 Management requirements

8.4.1.1 The Organization will identify all the stakeholders likely to express needs concerning the system over its entire lifecycle.

8.4.1.2 The Organization will ensure that it has up to date input documents expressing all the Acquirer's needs (for example: functional specifications, system Technical Specification (TS), etc.).

8.4.1.3 Throughout the iterative Acquirer expression of need process, the Organization will analyse the need expressed in order to determine its degree of maturity according to criteria of clarity, consistency, absence of ambiguity and completeness, for example by taking account of the scope of the requirements to be met (environment, operational scenarios, various constraints such as laws and regulations, etc.).

8.4.1.4 Similarly, the Organization will check the convergence of the maturity of this expression of need, in particular by analysing the following aspects:

- detection and expression of implicit requirements,
- detection of over-specification and under-specification in relation to the perceived real need,
- identification of requirements for which a compromise may be necessary or useful:
  - conflict between technical requirements,
  - optimization of the "performance/cost/schedule/risks" trade-off (for example: relative importance of the various requirements, performance margins or tolerances, etc.);
- identification of critical requirements linked to a technical risk at system level.

8.4.1.5 The Organization will ensure that the impacts of the operational requirements expressed (operating environments, system lifecycle, interfaces with the user and the higher level system, etc.) have been analysed for all the functions of the system.

8.4.1.6 The Organization will seek convergence with the Acquirer on a reformulated system requirements baseline (which could for example take the form of a system PTS) complying with the maturity criteria mentioned in 8.4.1.3.

8.4.1.7 In order to control the complexity, the Organization will check that the formulation of system requirements limits their degree of inter-dependency.

8.4.1.8 If the Acquirer need changes, the Organization will analyse the impact on the requirements baseline in terms of maintaining the maturity and feasibility criteria.

8.4.2 Elements of the management plan

8.4.2.1 The methods, tools and resources used for the analysis of the Acquirer needs are described.

8.4.2.2 All shortfalls, ambiguities, inconsistencies, etc., are reported to the Acquirer, so that the Acquirer can complete its expression of need.

8.4.2.3 The system interfaces with the operational environment and the higher level system are analysed, in order to ensure that they are correctly included in the specifications of the system and its components.

8.5 Requirements Validation

NOTE Some of the requirements of this activity are only really needed if the Organization drafts a system requirements document (for example a system PTS) separate from the document expressing the Acquirer's need (for example the system (N)TS).

8.5.1 Management requirements

8.5.1.1 The Organization will demonstrate that the system requirements fully reflect the need expressed by the Acquirer.

8.5.1.2 The Organization will check that the system requirements which are not directly derived from the Acquirer need are necessary and sufficient as induced by the design of the system.

8.5.1.3 The Organization will coordinate the requirements validation activities with the Suppliers who have been delegated responsibility for some system requirements.

8.5.2 Elements of the management plan

8.5.2.1 It is checked and validated with the Acquirer as early as possible that the end-user's needs are clearly understood, for example through simulation, models or mock-ups.

8.5.2.2 A traceability matrix is provided, justifying the complete coverage of the expressed need and highlighting the possible interdependences between requirements.

8.5.2.3 The availability of the human resources with appropriate competence in requirements engineering is planned, taking account of the time needed to acquire the necessary experience in this field.

8.6 Solution Definition

8.6.1 Management requirements

8.6.1.1 The Organization will describe the method used to define a system solution that meets the system requirements and will demonstrate its capability to implement this method.

8.6.1.2 The Organization will demonstrate that this method can be used to acquire definition states of the system solution which are compatible with the project phasing and scheduling (for example to guarantee the availability of the development specimen on the planned dates).

8.6.1.3 The Organization will provide a solution definition comprising:

a) a system architecture showing the system breakdown into sub-systems,

b) the allocation of system requirements into expressions of need at the sub-system level (e.g. sub-system (N)TS) according to the proposed architecture.

8.6.1.4 The Organization will demonstrate the traceability of the system requirements towards the sub-system requirements and the consistency of their allocation to the sub-systems.

8.6.1.5 The Organization will have assessed the feasibility of the sub-systems identified in the proposed solution concepts.

8.6.1.6 The Organization will demonstrate that the system definition meets the Acquirer requirements for interfacing with the higher level system.

8.6.1.7 The Organization will demonstrate that the definition of the sub-systems and their interfaces (without forgetting any existing or modified sub-systems that are reused) ensures:

a) that the system can be integrated, by controlling the compatibility of the interfaces,

b) that the expected system performance is met, after integration of the system.

8.6.1.8 If necessary the Organization will transfer to the lower level Suppliers the elements of the higher level expression of need to ensure that the needs as expressed by the Acquirer are clearly understood.

8.6.2 Elements of the management plan

8.6.2.1 The initial approach adopted for structuring the solution is the functional analysis. The need expressed by the Acquirer is thus broken down into functions and then successive sub-functions down to a functional level enabling the complexity to be reduced.

8.6.2.2 The adopted physical architecture is checked in order to ensure that it enables all the elements of the functional architecture to be projected into physical components that exist or are specifically designed.

8.6.2.3 The results of system level requirements allocation to the various components of the system architecture are recorded in a traceability matrix and these requirements are translated into sub-system needs.

8.6.2.4 A simulation model, comprising the definition of the sub-systems and their interfaces, is used in order to optimize the system definition process. This model includes the sub-models produced by the sub-systems Suppliers.

8.6.2.5 The additional requirements resulting from the system architecture and the analysis of the interfaces between the components are included in the sub-systems requirements baseline.

8.6.2.6 For each sub-system making up the system, a set of requirements is thus identified and must be consolidated. The initial consolidation step consists in checking their consistency with the other components requirements and with the system. The next consolidation step consists in drafting an expression of need at component level, negotiated with the designated Supplier (for example in the form of a consolidated sub-system (N)TS). In the case of an off-the-shelf component, this expression of need consists simply in drafting a procurement specification.

8.6.2.7 The physical environments encountered by each sub-system throughout its lifecycle are described as precisely as needed, as well as the non-functional requirements such as RAMS requirements, and if necessary, the expectations in terms of ergonomics and user interface.

8.7 Modelling/simulation

8.7.1 Management requirements

8.7.1.1 The Organization will describe its modelling strategy based on:

- the end purpose of the models supporting the other SE technical activities (Acquirer needs analysis, solution definition, requirements validation, etc.),
- the iterative nature of these activities during development,
- the ability to integrate models from the Suppliers of the Organization,
- the ability to integrate into models representative of the higher level system (e.g. take account of imposed solutions in terms of accuracy, choice of model, interface, nature and number of variables exchanged, etc.),
- the representativeness of the system lifecycle (storage, utilisation, transport, etc.),
- taking account of the complexity of the system (physical and logical architectures of the system, interfaces, etc.).

8.7.1.2

- the modelling assumptions (field of assumptions, boundary conditions, representativeness of models, etc.),
- the methods for analysing the simulation results,
- the simulation results and the accuracy of these results,
- the management of the input data and of the data resulting from use of the models.

8.7.1.3 The Organization will ensure the availability of the appropriate skills for the design and utilisation of the models.

8.7.1.4 The Organization will ensure that the models are robust and representative of the actual system and its environment.

8.7.1.5 The Organization will analyse the origin of discrepancies between the expected results and the results of the simulations and tests and will consequently define the actions necessary with regard to the models, the actual system or its Product Technical Specification.

8.7.2 Elements of the management plan

8.7.2.1 A standardized neutral format is used to exchange CAD mock-ups, in order to ensure the compatibility of the technical data exchanged as part of the Definition Files.

8.7.2.2 The various system representation models (behaviour, dimensions, etc.) needed at the various stages of system development are identified in a modelling plan.

8.7.2.3 A performance simulation model is developed based on the integration of the performance models for each of the sub-systems, in order to demonstrate the convergence of system performance throughout the project.

8.7.2.4 The breakdown of system performance into specifications of need for the sub-systems is supported by a model able to consolidate the requirements.

8.7.2.5 The models are fixed or improved by correlating their results with those of the verification and validation tests on a set of chosen key points in the operating range. The models are thus made reliable and can be used to predict the system performance at other points in the range which are not easily accessible during testing.

8.8 System analysis

8.8.1 Management requirements

8.8.1.1 Throughout the design process, the Organization may be required to analyse several alternative solutions (including some proposed by the Acquirer) in response to technical problems raised at a given stage (logical architectures, physical concepts and architectures, requirements allocations, detailed designs).

8.8.1.2 The Organization will provide an analysis report in order to compare the alternative solutions with each other with regard to the need compliance criteria and to guide the choice of the optimal solution.

8.8.1.3 The Organization will organize a specific review to enable the Acquirer to rule on the choice of the solution which will become a contractual reference for the rest of the development activities.

8.8.2 Elements of the management plan

8.8.2.1 The system analysis of the solutions is based on the analysis results obtained at the sub-systems level.

8.9 System verification

8.9.1 Management requirements

8.9.1.1 At each agreed step in the project phasing and scheduling, the Organization will check that the system definition meets the system requirements defined in the system PTS.

8.9.1.2 This verification will take place throughout the development, in particular at the design stage and when producing the development products.

8.9.1.3 This verification will be based on the proof obtained at the level of the system which the Organization is responsible for, as well as on the proof obtained at the lower levels.

8.9.1.4 The major risks linked to the verification (for example, availability of the test resources and development products) will be identified by the Organization, quantified and communicated to the Programme Management.

8.9.1.5 The Organization will define the internal organization and identify the responsibilities necessary for successful verification and production of the associated supplies.

8.9.1.6 If the verification results show that the product makes it impossible to meet one or more technical requirements, the Organization will investigate the causes and will propose to the Acquirer one or more corrective solutions after assessing their impact (performance, cost, schedule) on the system definition and on the project.

8.9.2 Elements of the management plan

8.9.2.1 A test logic is established to describe the verification method and the phasing and scheduling of the verification tasks, which allow acquisition of all the expected evidence and minimizes the risks and costs, and which aim at achieving the maximum synergy with the validation activities specified in the Definition Justification Plan (see 8.10).

8.9.2.2 This logic takes account of the following identified assumptions and constraints:

- the development plan, and thus the maturity of the system during its development,
- the representativeness of the test configuration (equipment from various contractors, conformity of interfaces, simulated or real test environment, accuracy and limitations of the test means, test scenarios, etc.),
- the availability of the equipment to be tested (development products),
- the availability of the test means, either existing or to be developed,
- a logic of gradually more complex tests accepting the risk of failure as a constructive contribution to the upstream development phases,
- etc.

8.9.2.3 The organization of this activity takes account of the following tasks related to verification:

- definition of verification-related plans,
- preparation, achievement and analysis of tests,
- management of the verification data and production of the test reports,

8.9.2.4 As part of this approach, the needs in terms of technical assistance and the associated skills are flown down to the Suppliers concerned.

8.10 System validation

8.10.1 Management requirements

8.10.1.1 Through the proofs resulting from the studies, simulations or tests, the Organization will ensure that the solution developed meets the needs of the Acquirer as expressed in the system (N)TS.

8.10.1.2 The Organization will deliver a Definition Justification Plan, submitted to the Acquirer for acceptance, that defines for each requirement in the system (N)TS the validation methods and tools which will be used to prove that the requirement is met within the expected performance margins.

8.10.1.3 The Organization will check that the validation work has been carried out in accordance with the Definition Justification Plan.

8.10.1.4 The Organization will deliver a synthesis document (for example Definition Justification File) recalling the list of requirements of the (N)TS and, for each one, stating the work (studies, tests, etc.) done and the results obtained, along with a commentary concerning the extent to which the requirement is met. This document is accompanied by an update of the project technical risks register.

8.10.2 Elements of the management plan

8.10.2.1 The validation results are analysed with the Acquirer in order to determine what the possible causes of operational dissatisfaction with the system are, for example: incomplete expression of need, incorrect interpretation of the expressed need, insufficient end-user skills, utilisation environment out of specifications, problem with system integration into the higher level system, performance defect in the system or its components, etc.

8.10.2.2 The Definition Justification File is built up along the development and is supplied to the Acquirer at the major milestones. This justification file is the subject of reviews with the Acquirer in order to validate the results obtained, assess the risks arising from these results and if necessary orient the subsequent validation work.

8.11 Processes in which the Systems Engineering is involved

The following processes are not strictly speaking an integral part of Systems Engineering:

- acquisition of components,
- integration of components into the system,
- supporting logistics development,
- transition to use.

These four upon activities are led by Programme Management, however, as, the SE is involved in these processes, a future edition of this document will aim to illustrate in a dedicated annex a few management requirements and elements of the MP characteristic of these activities.

9 Interfaces between Systems Engineering Management and the other Programme Management disciplines

NOTE This paragraph is an application of the project processes of ISO/IEC 15288:2008

9.1 General

The purpose of this Clause is to describe for each other discipline X of Programme Management:

a) the contribution of SE management to discipline X (ie. activity X1),

b) the X2 related activities not performed by SE management,

c) the X1 / X2 exchanges (information, services provided/expected).

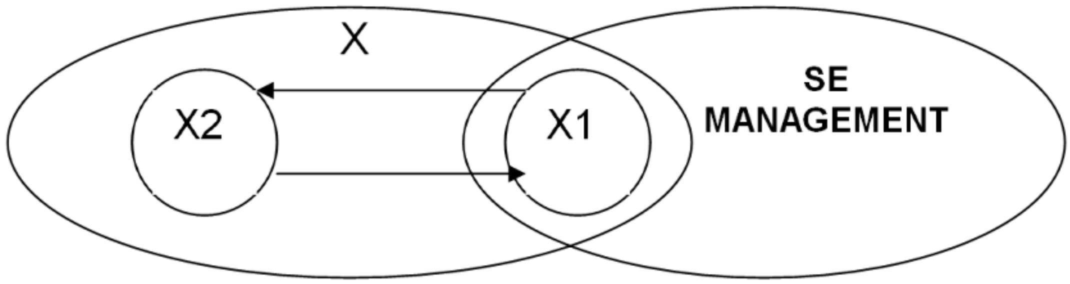

Figure 8 — Relations between SE Management and one of the other disciplines of Programme Management

This guide simply deals with the disciplines of Programme Management which have a specific interface with Systems Engineering (risk management, RAMS and Integrated Logistics Support).

9.2 Risk management

a) SE Management contributes to Risk Management through :

- identification of technical risks at system level through permanent re-assessment. This can be justified by the fact that SE management controls the technical activities which allow modelling, simulation, distribution, evaluation, etc. of changes of the technical characteristics of the system,
- evaluation of the technical risk at system level,
- consolidation of sub-system risks: a Supplier parameter or performance can entail a risk at system level,
- control of the technical risks management at Supplier level.

b) SE Management does not perform the following activities :

- risk management process aspects: definition and implementation of risk control methods and tools, monitoring of the risks portfolio, etc. are not necessarily the responsibility of SE management (for example: under the responsibility of Programme Management),
- consolidation of risks at project level is not the responsibility of SE management.

c) Information and services are provided and expected :

- by Risk Management:
  - risk management tools and methods (e.g.: risk monitoring sheet),
  - criticality scales,
  - decision concerning proposed preventive and corrective actions,
  - budgets allocated for risks,
  - control of margins (performance, schedule).

- by SE Management:
  - identification/management of technical risks,
  - measurement of criticality (impact at system level),
  - analysis of the impact on the sub-systems,
  - definition and control of technical risk mitigation action plans.

9.3 Configuration management

Configuration management is led by Program Management and related to suppliers agreements.

a) Contribution of SE management to this discipline:

- SE management is responsible of the definition of the agreement technical content,
- Structuration of the project (PBS, WBS, OBS) are technically dependant on the architectural design of the system.

b) Activities not performed by SE management:

- Decision making against the structuration of the project (PBS, WBS, OBS) taking into account the "make or buy decision", industrial strategy, environmental and legal constraints, etc.

10 Specialty engineering activities

NOTE This paragraph is an application of the Clause 9 of the INCOSE SE handbook. The ISO/IEC 15288:2008 does not address these issues.

10.1 Design to Cost

The deployment of system engineering benefits from being carried out by integrating the process of value management (EN 12973) and associated methods, including Design to Cost.

The contributions of the design to cost are in particular:

- the linking of the acquirer and the supplier in order to converge to a functional need that allows to find an answer within technical and cost satisfactory to both parties,
- an ongoing effort to implement the SE process appropriate to the current project phase,
- a rigorous evaluation of possible solutions and criteria for assessing the impacts of changes of needs and of technical choices.

10.2 Reuse or new solution

After analysis of the initial needs, of existing solutions and of the life cycle of the product to be delivered, architecting activities must evaluate the benefits of reuse compared to new solutions.

The aim is to assess the impact of different solutions against criteria as diverse as the expected performance, cost objectives (recurring and non-recurring), the period of commissioning, the risks, the need to address the obsolescence at short-term or long-term.

The Table 2 below shows a current trend of evolution of the impact of each criterion according to the maturity of the solution.

Table 2

	Reuse (change on current solution)	**New solution**
Performance	➲	⇑
Non recurring cost	⇓	⇑
Recurring cost	➲	⇓
Time to commissioning	⇓	⇑
Risk (Cost, schedule and performance)	⇓	⇑
Treatment of obsolescence in the short term	⇑ sharing possible with products in use	None
Treatment of obsolescence in the long term	⇑, could be impossible	➲

For a complex system or long-life system, the choice is usually the combination of existing subsystems and innovative subsystems.

The obsolescence management should be anticipated for both the reuse and for new solutions.

A solution including reuse must be compatible with the in-service duration or allow a later upgrade. This upgrade should be planned during a maintenance period for a new solution, the architecture must anticipate the management of obsolescence to allow upgrades or replacements of the potential obsolete subsystems. Disruptive technologies can be an opportunity to implement new solutions.

10.3 Human factors

The aim is to introduce in system engineering process a Human-centred design for interactive systems.

See Annex F "Mapping between systems engineering processes and Human-centred design for interactive systems processes and principles".

Annex A
(informative)

Areas covered by standards covering Systems Engineering

See Figure A.1.

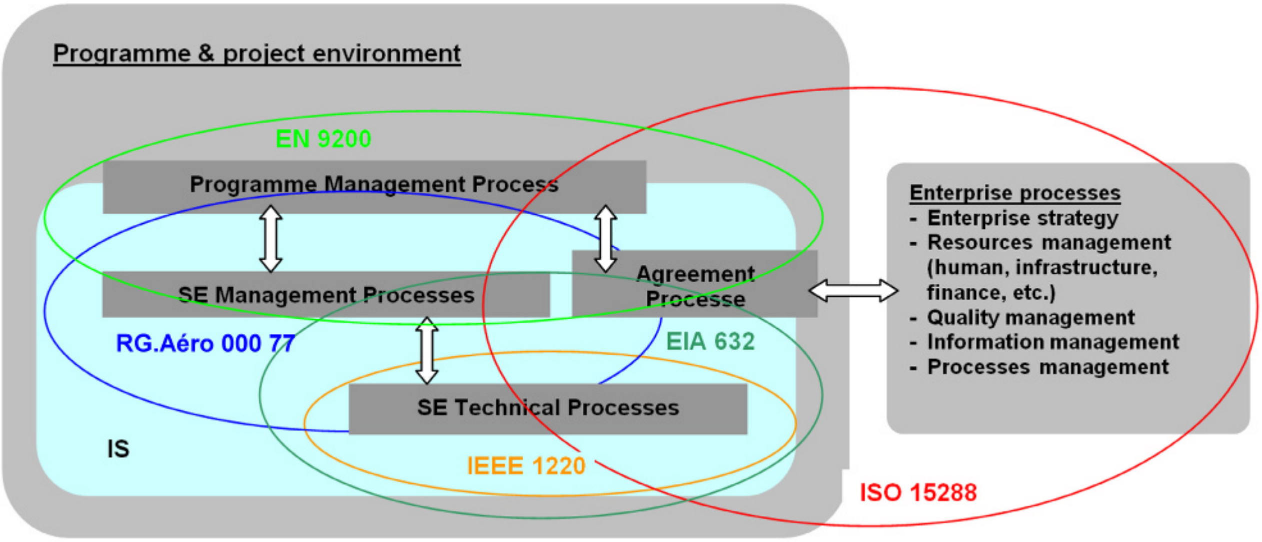

Figure A.1 — Areas covered by standards covering Systems Engineering

Annex B
(informative)

Method for identifying management requirements

B.1 "SE management generic requirements" table

See Table B.1.

Table B.1

PROCESS OBJECTS (I/O)		ACTIONS				
Generic objects	**Objects specific to the activity**	**PLAN** Identify Describe Select Schedule Plan Avoid Anticipate Define	**DO** Record Communicate Distribute Control Coordinate Advise Manage Decide Supply	**CHECK** Analyse Measure Assess Compare Verify Validate Approve Demonstrate Ensure	**ACT** Correct Improve Negotiate Update Optimize	**PDCA** Assure Control
Input data and products						
Criteria						
Assumptions						
Technical requirements (including constraints)						
Product interfaces						
Solution imposed (concept, hardware, etc.)						
Programme baseline						
Output products						
Documents						
Products (hardware and software)						
Services						
Results						
Resources						
Means and tools						
Infrastructures and environment						
Methods						
Human resources						
Organization						
Decisions / events / milestones						
Review						
Risks						
Managers						
Objectives (costs, schedule)						

Tasks						
Process interfaces						
Industrial organization						

B.2 Method for using the “SE Management generic requirements” table

B.2.1 For drafting SE management requirements

For each SE technical activity:

- in the table, identify the objects specific to the activity;
- in each of the headings, select the most pertinent objects determined according to the criteria of the list (see Table B.2);
- successively run through the columns corresponding to the SE management actions (PDCA) and identify the actions adapted to the objects chosen;

For each intersection: (see Table B.2);

- allocate a requirement identification number and note the most appropriate action verb;
- draft the corresponding requirement, introducing the specificities and terminology specific to the project and to the organizations involved in the programme.

EXAMPLE

- SE activity = “System Verification”,
- Object = “Document”,
- Action = “Supply”,
- Intersection chosen = “System verification: Supply X Document”,
- Management requirement MRxxx = “The Organization will supply a system verification plan, …,
- …/…

Table B.2

List of selection criteria

To determine those objects which require the expression of a management requirement, the following criteria may be used:
— pertinence for the considered activity;
— particular importance with respect to the System aspect:
    — control of iterations (plan, assess and monitor with a view to convergence),
    — reduction of complexity (of the product, of the activities, multiple participants),
    — organization of recursivity (set up the interfaces, guarantee the flows, maintain consistency between levels);
— requirement received from a higher level acquirer (level N+2) to be flown down towards the

Organization; — risk level related to the decision to clarify or not the considered management requirement; — etc.

NOTE 1 The table is a tool which can be customized by the user (specificities, own vocabulary, fields of competence, etc.) and can evolve (enhanced with lessons learned).

NOTE 2 The table identifies any absence of requirements, first of all at macro-object level (organization, resources, etc.) and then in terms of the objects according to the four PDCA management actions. An absence of requirements at macro-object level should be avoided.

NOTE 3 The terms “Control” and “assure” refer to the PDCA as a whole. They should be used when it is not necessary to give a detailed explanation for all or a part of the P, D, C, A (for example: case of an “open” management requirement for a “mature” Organization).

B.2.2 To draft elements concerning the SE management plan

- Step 1:
  - use the table in a way similar to that used to draft the requirements.
- Step 2:
  - ensure that the Acquirer's management requirements are covered by this analysis,
  - complete the plan if necessary,
  - enhance the table if necessary.

Annex C
(informative)

Implementation example: “solution definition” activity

C.1 Filled out table

See Table C.1.

Table C.1 *(1 of 2)*

PROCESS OBJECTS (I/O)		ACTIONS				
Generic objects	**Objects specific to the activity**	**PLAN** Identify Describe Select Schedule Plan Avoid Anticipate Define	**DO** Record Communicate Distribute Control Coordinate Advise Manage Decide Supply	**CHECK** Analyse Measure Assess Compare Verify Validate Approve Demonstrate Ensure	**ACT** Correct Improve Negotiate Update Optimize	**PDCA** Assure Control
Input data and products						
Criteria	Integration capability of the system					Assure 8.6.1.7 a)
	Satisfaction of expected performance					Assure 8.6.1.7 b)
	Traceability of sub-system requirements		Record 8.6.2.3	Demonstrate 8.6.1.4		
Assumptions	Feasibility of sub-systems			Assess 8.6.1.5		
Technical requirements (including constraints)	Acquirer need		Communicate 8.6.1.8			
	System requirements					
Product interfaces	Interface with higher level requirements			Demonstrate 8.6.1.6		
	Compatibility between sub-systems					
Solution imposed (concept, hardware, etc.)	Requirements expressed in terms of solution					
Programme baseline	Design rules					
Output products						
Documents	System Definition File		Supply 8.6.1.3			
	Sub-system (N)TS		Supply 8.6.1.3 b)		Negotiate 8.6.2.6	
Products (hardware and software)						
Services						
Results	System architecture		Supply 8.6.1.3 a)	Verify 8.6.2.2		
	Sub-system requirements	Identify 8.6.2.5				
		Identify 8.6.2.7				

Table C.1 *(2 of 2)*

PROCESS OBJECTS (I/O)		ACTIONS				
Generic objects	**Objects specific to the activity**	**PLAN** Identify Describe Select Schedule Plan Avoid Anticipate Define	**DO** Record Communicate Distribute Control Coordinate Advise Manage Decide Supply	**CHECK** Analyse Measure Assess Compare Verify Validate Approve Demonstrate Ensure	**ACT** Correct Improve Negotiate Update Optimize	**PDCA** Assure Control
Resources						
Means and tools	Design tools					
Infrastructures and environment						
Methods	Solution definition Functional analysis Object-oriented analysis	Describe 8.6.1.1 Select 8.6.1.2				
Human resources	Designers					
Organization						
Decisions/Events/ milestones	Reference for sub-systems design activity					
Review	CDR (Critical Design Review)					
Risks						
Managers	Organization					
Objectives (costs, schedule)	Compatibility with phasing and scheduling			Demonstrate 8.6.1.2		
Tasks						
Process interfaces	Modelling process					Assure 8.6.2.4
Industrial organization	Sub-systems partners					

C.2 Requirements and elements of the management plan

C.2.1 Management requirements (see 8.6.1)

The Organization will describe the method used to define a system solution that meets the system requirements *(PLAN: Describe X Methods: Solution Definition)* and will demonstrate its capability to implement this method (see 8.6.1.1).

The Organization will demonstrate that this method can be used to acquire definition status of the system solution which are compatible with the project phasing and scheduling (for example to guarantee the availability of the development specimen on the planned dates). *(CHECK: Demonstrate X Objectives: Compatibility with phasing and scheduling)* (see 8.6.1.2).

The Organization will provide a solution definition *(DO: Supply X Documents: System Definition File)* (see 8.6.1.3) comprising:

a) system architecture showing the system breakdown into sub-systems, (DO: Supply X Results: System Architecture),

b) the allocation of system requirements into expressions of need at the sub-system level (e.g. sub-system (N)TS) according to the proposed architecture. (DO: Supply X Documents: Sub-system (N)TS).

The Organization will demonstrate the traceability of the system requirements towards the sub-system requirements and the consistency of their allocation to the sub-systems*. (CHECK: Demonstrate X Criteria: Traceability of sub-system requirements)* (see 8.6.1.4).

The Organization will have assessed the feasibility of the sub-systems identified in the proposed solution concepts. *(CHECK: Assess X Assumptions: Feasibility of sub-systems)* (see 8.6.1.5).

The Organization will demonstrate that the system definition meets the Acquirer requirements for interfacing with the higher level system. *(CHECK: Demonstrate X Product interfaces: Interface with higher level requirements)* (see 8.6.1.6).

The Organization will demonstrate that the definition of the sub-systems and their interfaces (without forgetting any existing or modified sub-systems that are reused) (see 8.6.1.7) ensures:

a) that the system can be integrated, by controlling the compatibility of the interfaces, (PDCA: Assure X Criteria: Integration capability of the system),

b) that the expected system performance is met, after integration of the system. (PDCA: Assure X Criteria: Satisfaction of expected performance).

If necessary the Organization will transfer to the lower level Suppliers the elements of the higher level expression of need to ensure that the needs as expressed by the Acquirer are clearly understood. *(DO: Communicate X Technical Requirements: Acquirer Need)* (see 8.6.1.8).

C.2.2 Elements of the management plan (see 8.6.2)

The initial approach adopted for structuring the solution is the functional analysis. The need expressed by the Acquirer is thus broken down into functions and then successive sub-functions down to a functional level enabling the complexity to be reduced. *(PLAN: Select X Method: Functional analysis)* (see 8.6.2.1).

The adopted physical architecture is checked in order to ensure that it enables all the elements of the functional architecture to be projected into physical components that exist or are specifically designed. *(CHECK: Verify X Results: System architecture)* (see 8.6.2.2).

The results of system level requirements allocation to the various components of the system architecture are recorded in a traceability matrix and these requirements are translated into sub-system needs. *(DO: Record X Criteria: Traceability of sub-systems requirements)* (see 8.6.2.3).

A simulation model, comprising the definition of sub-systems and their interfaces, is used in order to optimize the system definition process. This model includes the sub-models produced by the sub-system Suppliers. *(PDCA: Assure X Process Interfaces: Modelling Process)* (see 8.6.2.4).

The additional requirements resulting from the system architecture and the analysis of the interfaces between the components are included into the sub-systems requirements baseline. *(PLAN: Identify X Results: Sub-system requirements)* (see 8.6.2.5).

For each sub-system making up the system, a set of requirements is thus identified and must be consolidated. The initial consolidation step consists in checking their consistency with the other components requirements and with the system. The next consolidation step consists in drafting an expression of need at component level, negotiated with the designated Supplier (for example in the form of a consolidated sub-system (N)TS). *(ACT: Negotiate X Documents: sub-system (N) TS).* In the case of an off-the-shelf component, this expression of need consists simply in drafting a procurement specification. (see 8.6.2.6).

The physical environments encountered by each sub-system throughout its lifecycle are described as precisely as needed, as well as the non-functional requirements such as the RAMS requirements, and, if necessary, the expectations in terms of ergonomics and user interface. *(PLAN: Identify X Results: Sub-system requirements)* (see 8.6.2.7).

Annex D
(informative)

Description of SE process activities

D.1 Expression of need by the Acquirer

Activity conducted by the Acquirer with the aim of producing an expression of need which can run from initial identification of the operational need in terms of system missions (for example user functional requirements) up to a formalization of this need as completely and precisely as possible (for example a System (Need) Technical Specification (N)TS), in particular characterizing the expected functions of the system, the environments encountered by the system during its lifecycle, the system external interfaces and the solutions or solution concepts imposed by the Acquirer.

D.2 Acquirer's needs analysis and system requirements definition

Activity conducted by the Organization jointly with the Acquirer, with the aim of ensuring that the expression of need by the Acquirer is fully and unambiguously understood by the Organization.

Carried out iteratively with the expression of need activity, it can lead to improve the quality of the Acquirer's requirements baseline by identifying gaps, inaccuracies, ambiguities, etc., until it provides the baseline of input requirements for the solution definition activity (for example, consolidated System (N)TS).

If this activity is carried out independently by the Organization, it leads to the definition of a system requirements baseline internal to the Organization (for example System Product Technical Specification PTS) able to establish a traceability link between the expression of need by the Acquirer and the solution definition.

D.3 Requirements validation

Activity conducted by the Organization and the Acquirer with the aim of ensuring that the requirements baseline produced by the Acquirer needs analysis and System requirements definition activity achieves the required quality criteria such as: completeness with respect to Acquirer need, absence of unjustified requirements (the exact need), clarity and unambiguity, verifiability, identification of critical requirements, consistency with flown down requirements, etc.

Depending on the output of the Acquirer needs Analysis and System requirements definition activity, the product of this activity is for example a consolidated and validated System (N)TS or a validated System PTS.

D.4 Solution definition

Activity conducted by the Organization with the aim of defining the Product Breakdown Structure and converting the system requirements into needs concerning the sub-systems (for example, sub-system (N)TS) and their interfaces (for example Interface TS).

This activity is directly based on the system analyses, system architecture and requirements allocation activities which have to justify the requirements breakdown logic, and the choices and compromises made by the System Architect.

D.5 Modelling and simulation

This activity, conducted by the Organization, accompanies all the SE processes from expression of need by the Acquirer up to transition to use and its aim is to produce and run models (for example mathematical models or mock-ups) representative of the system in support of Acquirer needs analysis, solution definition, etc. Using models is for example a way of comparing solution concepts, exploring at lower cost the system field of operation and performance, replacing missing physical systems or sub-systems, analysing test results, etc.

Another example of application is the numerical model which can be used for upstream of manufacturing in order to check that the system can actually be produced.

D.6 System analyses

Set of studies conducted by the Organization, in support of the design activities and in particular based on the modelling/simulation activity. It produces system study results (for example justification of architectural choices, system performance envelope, characterization of sub-systems thermal and vibration environments). These studies in particular comprise:

- comparative analyses of alternative solutions,
- compromise/trade-off/optimization analyses within a given field of constraints,
- technical risk analyses at System level.

Joint Acquirer – Organization work could be desirable, in particular in the Expression of need and Solution definition phases, for example to make it easier to identify trade-offs with the higher level system.

In this case, the distribution of roles can be specified contractually (for example: integrated team, shared working environment).

D.7 System verification

Activity conducted by the Organization with the aim of checking that the system definition meets the System requirements resulting from the “Acquirer needs analysis and System requirements definition” activity.

This activity can be backed up by:

- theoretical verifications,
- simulations on virtual models,
- tests on physical mock-ups,
- use of sub-system verification elements which are conclusive at system level,
- tests on the final system.

During verification, the Organization is in charge of organizing and performing work in accordance with its own procedures. This task is generally performed at the Organization's facilities.

D.8 System validation

Activity conducted by the Organization under the responsibility of the Acquirer, with the aim of demonstrating that the system meets the actual operational needs of the end-user Acquirer, in its own environment.

During validation, the Organization is in charge of organizing and performing work in accordance with the procedures agreed with the Acquirer (location, scheduling, means, etc.).

From a strictly contractual viewpoint, validation is for the Organization expressed more in terms of means requirement (for example, level of participation in the validation work and the resources committed) than in terms of result requirement. It is typically run in partnership with the Acquirer, in a context that is gradually closer to the Acquirer's actual operational scenarios and environment.

As the Acquirer's actual need is only materialized through the baseline expression of need (consolidated system (N)TS), the validation work is carried out with respect to this baseline. Therefore, in certain cases when discrepancies are detected with the actual operational need, system validation can lead to a change to the system (N)TS: detection of over-specification (performance higher than actual needs), validation of ergonomics and Man Machine Interface, etc.

Annex E
(informative)

Description of certain objects in the SE process

Function-tree
Representation of the product or the system showing the breakdown structured in functions and sub-functions which must be fulfilled by successive product levels. The functional levels do not necessarily coincide with the product levels.

Product-tree
Tree **representation** of the product or the system showing its breakdown in successive levels in which the elements are less and less complex.

System architecture
Fundamental organization of a system embodied in its components, their relationships to each other and to the environment, and the principles guiding its design and evolution.

Functional architecture
Description of the system in the form of an arrangement of functional modules and their interactions which defines their execution sequencing, the conditions for control or data-flow and the performance requirements in order to satisfy the requirements baseline.

Physical architecture
Description of the system in the form of an arrangement of physical elements (hardware, software, data, etc.) and the link network between these elements (interfaces, data-flows). This arrangement is the result of projecting functional models onto physical elements.

Development specimen
Product close to the end-product and foreshadowing the serial production, but used provisionally for development purposes before being returned to the production line.

Annex F
(informative)

Mapping between systems engineering processes and Human-centred design for interactive systems processes and principles

F.1Mapping with ISO/IEC 15288:2008 Technical processes

See Table F.1.

Table F.1

UCD processes ISO 9241-210	**System life cycle processes** – ISO/IEC 15288:2008										
	Stakeholders requirements definition process	Requirements analysis process	Architectural design process	Implementation process	Integration Process	Verification Process	Transition Process	Validation Process	Operation Process	Maintenance Process	Disposal Process
Understand and specify the context of use	☑	☑						☑	☑		☑
Specify the user and organizational requirements	☑	☑						☑	☑	☑	☑
Produce design solutions	☑	☑	☑	☑							
Evaluate the design against requirements	☑	☑				☑		☑	☑		

F.2Mapping with ISO/IEC 15288:2008 others processes than technical ones

See Table F.2.

Table F.2

UCD processes ISO 9241-210	**Systems life cycle processes –** ISO/IEC 15288:2008											
	Organizational Project-Enabling Processes					**Project Processes**						
	Life Cycle Model Management Process	Infrastructure Management Process	Project Portfolio Management Process	Human Resource Management Process	Quality Management Process	Project Planning Process	Project Assessment and Control Process	Decision Management Process	Risk Management Process	Configuration Management Process	Information Management Process	Measurement Process
Planning of user-centred design activities	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑
Multi-disciplinary design	☑	☑		☑			☑		☑		☑	
Active involvement of users; clear understanding of user and task requirements	☑	☑	☑	☑	☑	☑			☑			
Iteration of design solutions	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑	☑

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