GRANULARITY CONCEPTS AND PRINCIPLES

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Abstract	For defining an architecture the granularity has to be decided. That is to say, to which extent modularization shall be performed in the system. This document provides criteria for defining sub-systems in an architecture and shall be a guideline to be used by the domains of the system pillar in defining their architecture.
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2 Purpose of the document

SPT2ARC-1215 - The CBO (Common Business Objectives) of the system pillar considers the modularity approach as a mean of improving the development, the deployment and the operation of any railway sub-systems, in particular ERTMS.
Modularization consists in defining sub-systems with harmonised interface. The size of the sub-systems and the number of interfaces between these sub-systems may vary at the moment. When it comes to defining the CCS/railway system architecture, one of the main topics is the granularity. That is to say, to which extent modularization shall be performed in the system.

SPT2ARC-1216 - There is a trade-off to be found between the size and functions of the sub-systems, the costs, the planning of development and the benefits that can be obtained and between the probability not to get the expected benefits and the overall complexity that drive risks.

SPT2ARC-1217 - The purpose of the present document is to provide criteria for defining the sub-systems. The document shall be used as a guideline for other domains.

SPT2ARC-1301 - This document shall give guidance in a harmonised architecture for the decision if new subsystems shall be created or not and for the decision to harmonise interfaces.

SPT2ARC-1218 - The document also highlights the CBO (Annex 1) and the user needs to give the rational underlying these criteria.

SPT2ARC-1214 - For that purpose the document contains the following steps:

1.) Basis: Definition of granularity concepts can be found in section 4 SPT2ARC-416 - Granularity Concepts.

2.) Problem statement: Section 5 SPT2ARC-415 - Problem statement specifies the problem and related pain points.

3.) Objectives: The objectives in section 6 SPT2ARC-422 - Granularization Objectives and Principles describe the why and what and give criteria to choose the architecture concerning granularity (e.g. reduce costs). The objectives are based on the overall CBOs objective and are more detailed objectives applicable for granularity choice.

4.) Principles: Section 6 SPT2ARC-422 - Granularization Objectives and Principles contains also the principles which specify how the objectives shall be achieved (e.g. ensure competition).

5.) Rules: Section 7 SPT2ARC-426 - Decomposition rules contains the modularisation granularity rules which show how to fulfil the objectives (which are a guideline, detailed rules; final checklist) (e.g. all interfaces are harmonised).

3 Applicability

SPT2ARC-1211 - This document applies to every domain of the System Pillar which has to deliver a piece of the architecture. The criteria specified in the present document shall be considered for decisions related to decisions for the CCS/railway system architecture (on-board and trackside) .

4 Granularity Concepts

This paragraph gives a definition of the concepts considered in granularity discussions.

SPT2ARC-1249 - To improve the understanding of the different granularity level, the diagram hereunder illustrates the relations between the concepts of functional apportionment / Interoperability / Exchangeability / Interchangeability which are among the main concepts defined in the present section:

SPT2ARC-1592 -

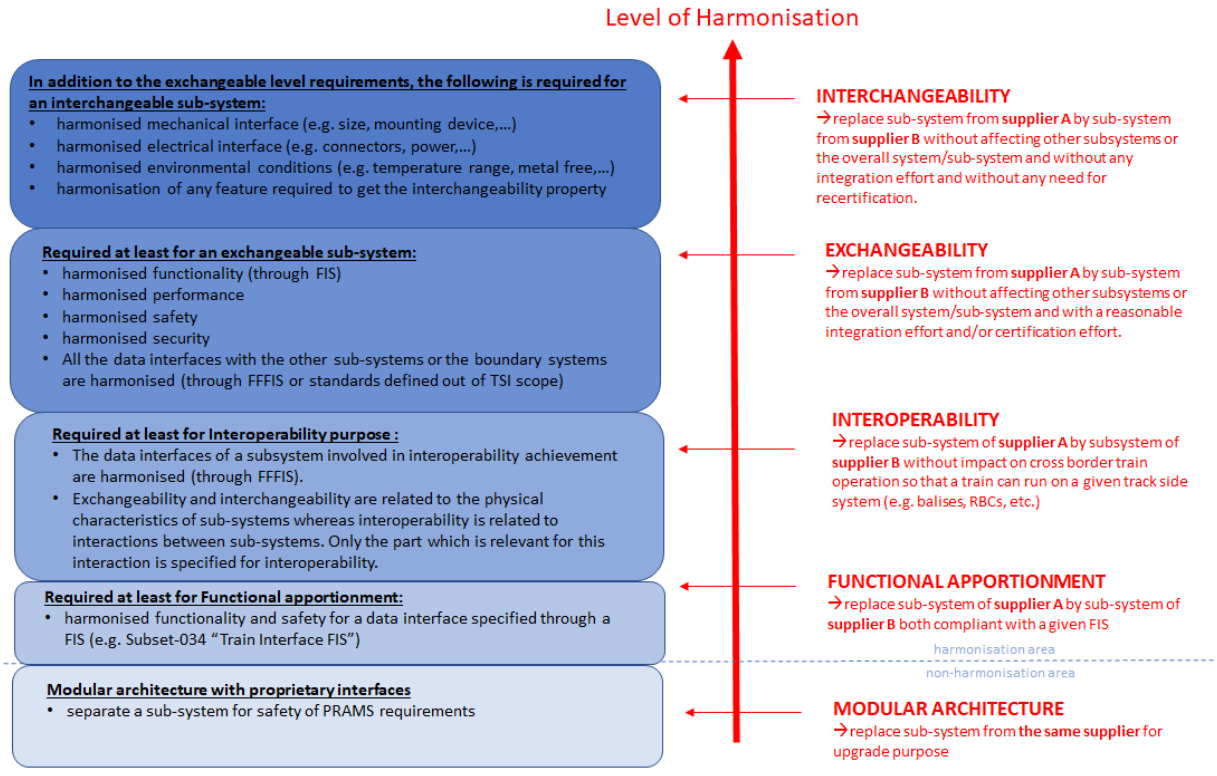

Figure 1: Levels of Harmonisation

SPT2ARC-1613 - Remark for SPT2ARC-1592 - Figure #: Levels of Harmonisation: In addition also core harmonisation is possible, in case there is an interface which is partly interoperable/exchangeable and is partly proprietary (optional or customisable parts). When two sub-systems use this interface, they have at least always the basic mandatory part of the interface to offer a basic functionality.

SPT2ARC-1591 -

Table 1: Levels of Harmonisation

	MODULARITY	FUNCTIONAL APPORTIONMENT	INTEROPERABILITY	EXCHANGEABILITY	INTERCHANGEABILITY
Replace sub-system from the same supplier for upgrade purpose	X	X	X	X	X
Separate a sub-system for safety or PRAMS requirements	X	X	X	X	X
Replace sub-system of supplier A by sub-system of supplier B both compliant with a given FIS		X	X	X	X
Harmonised functionality and safety for a data interface specified through a FIS (e.g. Subset-034 "Train Interface FIS", in case of existing vehicle designs in TSI 2023)		X	X	X	X
Replace sub-system of supplier A by sub-system of supplier B without impact on cross border train operation / impact on normal service so that a train born system can run on a given track side system (e.g. balises, RBCs, etc.)			X	X	X
The data interfaces of a sub-system involved in interoperability achievement are harmonised (through FFFIS)			X	X	X
Harmonised functionality (through FIS) for interoperability			X	X	X
Harmonised performance for interoperability			X	X	X
Harmonised safety for interoperability			X	X	X
Harmonised security for interoperability			X	X	X
Replace sub-system from supplier A by sub-system from supplier B without affecting other sub-systems or the overall system/sub-system and with a reasonable integration effort and/or certification effort				X	X
All the data interfaces with the other susbystems or the boundary systems are harmonised (through FFFIS or standards defined out of TSI scope)				X	X
Harmonised functionality (through FIS) of the sub-system				X	X
Harmonised performance of the sub-system				X	X
Harmonised safety of the sub-system				X	X
Harmonised security of the sub-system				X	X
Replace sub-system from supplier A by sub-system from supplier B without affecting other sub-systems or the overall system/sub-system and without any integration effort and without any need for recertification.					X
Harmonised mechanical interface (e.g. size, mounting device,...)					X
Harmonised electrical interface (e.g. connectors, power,...)					X
Harmonised environmental conditions (e.g. temperature range, metal free,...)					X
Harmonisation of any feature required to get the interchangeability property					X

Adaptability

Adaptability refers to the ability to adjust a system in response to changes in its environment or changes of requirements. It involves a broader concept of flexibility and resilience, encompassing not only modifications to the system itself but also its capacity to accommodate evolving needs or external factors. An adaptable system can respond effectively to new technologies, market demands, user expectations, or regulatory changes.

CAPEX

Capital Expenditures or Capital Expenses

Changeability

Changeability refers to the ease with which a system can be modified or customized to meet specific

requirements or adapt to new circumstances. It encompasses both minor changes, such as configuration adjustments, and more substantial modifications, such as adding or removing sub-systems.

Evolvability

Evolvability is the ability to easily adapt to new technologies or to extend the functionality of the CCS system without the involvement of the original supplier.

Exchangeability

Exchangeability is the ability to replace a sub-system from supplier A by a subsystem from supplier B without affecting other sub-systems or the overall system/subsystem and with a reasonable integration effort and/or certification effort. Exchangeability and interchangeability are related to the physical characteristics of sub-systems whereas interoperability is related to interactions between sub-systems (e.g. also between STM and ETCS on-board there is interoperability).

FIS - Functional Interface Specification

Functional requirements and description of an interface. This clarifies also the functional apportionment and related safety requirements of the two sub-systems of the interface.

FFFIS - FORM FIT FUNCTIONAL INTERFACE SPECIFICATION

A FFFIS is the complete definition of an interface between functional or physical entities.
The FFFIS includes:
- FIS,
- Electrical characteristics related to data,
- communication protocol,
- and including connector and plug.

The FFFIS and accompanying documents (e.g. safety analysis) guarantees the interoperability but not the exchangeability of physical entities, see Subset-037 SPT2ARC-1620.

Functional apportionment

Functional apportionment is the clear assignment of functions to sub-systems. It is an architectural choice supporting the ability to replace a sub-system of supplier A by a subsystem of supplier B both compliant with a given FIS.

Granularity

The granularity characterises the level of modularity of a system. The more subsystems a system is composed of, the higher its granularity.

Granularization

The granularization refers to system engineering activity aiming at defining granularity.

Harmonisation

Harmonisation includes the options TSI specification (Annex A or Application Guide), Standardisation via ESO, or agreed System Pillar Publication.

Interchangeability

Interchangeability is the ability to replace a subsystem from supplier A by a sub-system from supplier B without affecting other sub-systems or the overall system/subsystem and without any integration effort (lowest reasonable integration effort) and without any need for recertification. Exchangeability and interchangeability are related to the physical characteristics of sub-systems whereas interoperability is related to interactions between subsystems (e.g. also between STM and ETCS on-board there is interoperability).

Interoperability

Interoperability means the ability to allow the safe and uninterrupted movement of trains that accomplish the specified levels of performance, see [Subset-023] SPT2ARC-1619 and [IOP-Dir 2016/797] SPT2ARC-1617 so that a train is able to run across different infrastructure networks (IMs) and that an infrastructure network is able to interact with trains of different Railway Undertakings, using systems/sub-systems from different origins. Exchangeability and interchangeability are related to the physical characteristics of sub-systems whereas interoperability is related to interactions between subsystems (e.g. also between STM and ETCS on-board there is interoperability).

Interface

With an interface the sub-systems of different suppliers are combined.

Maintainability

Ability to be retained in, or restored to, a state to perform as required, under given conditions of use and maintenance [EN50126] SPT2ARC-1616 .

Modularity

Modularity is used in this document as a general term for dividing a system/sub-system/module in sub-systems/modules.

Reusability

The property of a sub-system to be integrated without any modification inside various CCS possibly deployed in different operation contexts.

Opex
Operational Expenditures

Scalability
Scalability refers to the ability of a system/sub-system to handle an increasing workload or expand its capacity without significantly impacting performance, efficiency, or cost.

SSI
Standard Security Interface

Sub-system (sometimes called "Building Block")
Sub-systems are along ARCADIA systems on System Level 5. Not to be confused with sub-systems in the TSI / interoperability directive. In the TSI / interoperability directive context a sub-system shall be regarded as a interoperability constituent
A sub-system is a part of a system, which is not split into smaller entities. It represents a leaf element in the hierarchy of systems-of-systems.
Physically speaking, a sub-system is either a piece of hardware plus software, or just a piece of software.
A sub-system is a source able unit of the CCS system, in particular:

- a sub-system can be individually tendered to a supplier,
- a sub-system can be built individually by a supplier,
- a sub-system must be integrated into a system, which includes all necessary test, verification, certification and validation activities depending on the level of harmonisation.

The harmonisation of the sub-system's features is to be defined according to the requested level:

- Functional Apportionment,
- Interoperability,
- Exchangeability, or
- Interchangeability.

Testability
A sub-system that is not designed for testability will not be ready to show that it fulfils the requirements needed by the overall system. Testability is not an attribute of the sub-system/module itself but has to be designed into architecture and interfaces.

Updateability
Updateability refers to the ability of a system to receive and incorporate updates or patches, e.g. to address security vulnerabilities. Updates are often provided to improve the performance of the system, stability, or security without introducing significant changes to its functionality.

Upgradeability

Upgradeability refers to the ability of a system to undergo significant enhancements or improvements in terms of its features, functionality, or performance. Upgrades typically involve the installation of a newer version or release of the system that offers new capabilities or improved performance compared to the previous version.

SPT2ARC-1623 - For further definitions see [SEMP - Annex B] SPT2ARC-1621.

5 Problem statement

SPT2ARC-1205 - Today railway undertakings and infrastructure manager are unable to afford the upgrade to ERTMS and cannot realise the potential benefits. This is in partly due to high lifecycle costs (LCC), caused by many factors. Supplier LCC are high including supporting bespoke products and high cost of goods sold (COGS), which leads to higher prices for the railways. There are many aspects why this is happening, but a more harmonised approach would lead to commoditisation and reduced costs . A more harmonised system approach shall enable the upgrade to ERTMS and access to all the advantages that come with it. Such an approach could indeed ensure the reduction of the life cycle costs of ERTMS solution by avoiding any bespoke function or product to implement on projects.

SPT2ARC-1204 - Two of the European railway sector's goals, concerning the CCS system, are protection of investments and an adaptable approach to deal with system upgrades while facilitating the growing / changing (market) demands to the railway transport system in a world where technology is rapidly evolving, see [Subset-150] SPT2ARC-1615 .

SPT2ARC-1206 - This can be achieved with CCS upgradeability and a simplification of system integration to be able to ease the integration of functional building blocks / sub-systems of the CCS system from different vendors. This is relevant for the initial system deployment as well as adapt/replace/update/upgrade the system.

SPT2ARC-1221 - The major blocking point to achieve these goals is the lack of full harmonisation of most the of the processes, functions and interfaces in- or external to the CCS system and a missing concept for modularisation and which interfaces shall be harmonised.

SPT2ARC-1219 - Manageable integration comes along with modularity, i.e. the separation of sub-systems of the CCS system architecture, their independent specification and complete definition of the interfaces.

Further problems are, see [SP-Report] SPT2ARC-1625 :

SPT2ARC-1223 - Forced early replacements or complete replacements because of component incompatibility increase the overall CCS cost

SPT2ARC-1222 - Missing harmonisation may lead to low market volumes per product which reduces the amortisation of innovation developments

SPT2ARC-1224 - The lifespan of technical solutions and products is more and more decreased because they are not fitting to their digital environment

5.1 Benefits of decomposition

There are several benefits of harmonised modularity and harmonised interfaces, as e.g. (see [ERJU SP - ARC - OCORA] SPT2ARC-1614 and [Subset-150] SPT2ARC-1615):

SPT2ARC-1240 - Modularity is a parameter of the system architecture. It allows to breakdown a large complex system into smaller and manageable sub-systems (**less complex sub-systems**).

SPT2ARC-1239 - Benefits for **simplification of system integration** to be able to ease the integration of functional building blocks of the CCS system from different vendors or one vendor based on harmonised interfaces.

SPT2ARC-1241 - Benefits for **adaptability, changeability, updateability** and **upgradeability**

- In case of patching and error corrections in Basic Integrity and SIL areas (e.g. cyber-security patching)
- In case of baseline upgrades (e.g. ETCS baseline 2 to 3)
- In case of functional enhancements (e.g. adding ATO functionality)
- In case of obsolescence
- In case of adaptation to new technologies (e.g. FRMCS for which modularity could contribute to a smooth upgradeability)
- In case of improving diagnostics

SPT2ARC-1231 - Benefits for **maintainability** : When a system encounters issues, failures or bugs, decomposition helps in isolating and localizing the problematic areas. It becomes easier to identify the specific module causing the problem, leading to quicker troubleshooting, debugging, update, replacement, repair and maintenance and block wise testing and validation of subsystems (simpler test benches).

SPT2ARC-1229 - Benefits for **exchangeability**: A sub-system can be replaced by another one with reasonable integration effort**.**

SPT2ARC-1234 - Benefits for **migration:** Sub-systems are individually migratable (introducing bug-fixes, improvements, new functionality), without affecting the other sub-systems, unless changes on external interfaces are needed that are not backward compatible (note: backward incompatible changes must be avoided, if possible).

SPT2ARC-1256 - Benefits for **evolvability:** Sub-systems support the evolvement of the overall CCS system (introduction of new technologies and functional enhancements). Decomposition enables different life-cycle profiles of the different constituents (e.g. vehicle vs. ETCS vs. connectivity) (note: this requires also the interface to evolve). Effort shall be made to avoid incompatible changes.

SPT2ARC-1254 - Benefits for **scalability**: Decomposing a system into modules of reasonable size enables economic beneficial scalability and reusability. The segregation of systems into smaller modules for scalability and reusability reasons shall base on real use cases backed up by business cases. If the system needs to be expanded or modified, it is easier to add or modify specific modules rather than the entire system in case of

once a modification is introduced, interfaces between the modified module and the rest of the subsystem is not modified. In case of once a modification is introduced, interfaces between the modified module and the rest of the subsystem is not modified .

SPT2ARC-1252 - Benefits for **competition in the market**: Smaller sub-systems allow more suppliers to compete. The problem per sub-system is smaller and can be solved (i.e. a product can be provided) even if a particular supplier is not able to develop the entire CCS system. Also, the subdivision of the entire system into smaller components/sub-systems require a better specification, so that implementing should be easier. This is increasing competition in the market. Benefits for testability: With smaller harmonised subsystems there is the opportunity to capitalize (and solve) on the return of experience on failures having common occurrence.

See also the extensive description of objectives for granularity definition in section 6.

5.2 Risks of decomposition

But a too much and one-sided focus on the benefits must be avoided. Drawbacks, negative impacts of granularity and level of decomposition has to be considered also and must not be underestimated (see [Subset-150] SPT2ARC-1615), as for example:

SPT2ARC-1248 - Manageability of dependencies of subsystems: Many conditions can arise through the interactions of the sub-systems, which might not be fully understood when the sub-system and its related interfaces are being specified. The changing of interfaces would result in high efforts (e.g. specifications, test specifications and safety cases).

SPT2ARC-1246 - Complexity of integration on customer level: The more sub-systems there are, the bigger is the responsibility of the system integrator might be unclear and may evolve for safe integration of the specific application, especially if the sub-systems are supplied by different vendors. The role and responsibility of a system integrator may evolve in these new schemes .

SPT2ARC-1245 - Quality assurance for sub-systems: For integration of modules of different vendors there is a risk if there are new vendors in the market who have not yet demonstrated the quality of their work in this context. Methods should be put in place to make sure that all suppliers use the same level of quality assurance.

SPT2ARC-1244 - Maintenance of specifications: Also, higher modularity may increase asynchronous evolution, where one sub-system changes without the related necessary changes in other sub-systems. Changes to sub-systems shall be carefully designed, but considerations of their effects on other sub-systems of the sub-system may be neglected or inadequate. Asynchronous evolution can be prevented by adequate documentation of constraints, conditions and assumptions and by checking before changes are performed to determine if the constraints, conditions and assumptions are violated by the change. In addition, very detailed interface specifications are required. The sector must not underestimate the effort on maintenance of the related specifications if modularity is increased to a certain extend. With new interfaces, the impact analysis at standard level increases. Therefore, there is a need of mature standards as a condition. Any component or module in the overall system does not have to only support the operational connectivity, it must also support the connectivity to the central services like: diagnostics, configuration (maintenance + SW updates/patching) and security. It has to be noted that also large building blocks have issues with maintenance of specifications (e.g. the current ERTMS specifications). So the right balance for granularity has to be found.

SPT2ARC-1243 - Unnecessary harmonisation of design details: There must not be unnecessary demands on how to build the system or sub-systems which could lead to limitation of innovation or increase development costs. How a system is built is a core competence of the suppliers and relevant for competition.

SPT2ARC-1242 - Complexity in certification and authorisation: On the one hand certification and authorisation could be more complex if by the creation of sub-systems a high dependency and interrelation between the subsystems is created. Weak documentation and rules on defining a sub-system may lead to difficulties in reusing the authorization of sub-systems. On the other hand, minor change in the an large subsystem causes a re-authorisation of the complete system. So, the right balance of granularity is needed.

SPT2ARC-1238 - Potential Performance Issues: In certain cases, decomposing a system may introduce additional overhead due to communication, data transfer, or coordination between components. This can impact system performance if not properly addressed during the design and implementation stages. It has to be ensured that the interfaces are not a bottleneck slowing down the system.

SPT2ARC-1237 - Limitation for innovations: Harmonised FFFIS interfaces may be a limitation for innovations and cause high cost when there is the need to change the FFFIS (new data). A FFFIS cannot be flexible for continues change.

SPT2ARC-1236 - Obstacle for innovations: There might be an impact on the ability to bring innovation on subsystem level in case of too low level of granularity.

SPT2ARC-1235 - Delay the emergence of next technologies: Due to long lasting harmonisation of new subsystems or interfaces which is not available in time there is the risk to delay the introduction of new technologies.

SPT2ARC-1233 - Lack of business case: Lack of business case e.g. in case of rework of pre-existing systems due to decomposition which requires significant effort.

SPT2ARC-1296 - Economical and technical impact of decomposing existing sub-systems: Decomposing existing sub-systems might have an economical and technical impact which has to be taken into account.

See also further risks in the description of objectives for granularity definition in section 6 SPT2ARC-422 .

SPT2ARC-1232 - Therefore, a sense of proportion shall be applied when the sector decomposes the system into sub-systems. The introduction of modularity shall be well balanced as desirable qualities such as interchangeability tend to go along with increased complexity at the system integration level. Sub-systems / building blocks must be kept to a reasonable number.

5.3 Relation between costs and level of decomposition

SPT2ARC-1230 - Some representatives of the railways tend to aim for a high level of decomposition, while some representatives of the industry aim for a lower level of decomposition. But no one knows/can predict where is the cost optimum between the level of granularity and CCS level costs. A business case / economical model is needed for whatever is agreed, see also [OCORA-BWS06-010] SPT2ARC-1622 .

SPT2ARC-1228 - If we have a too low level of granularity or a too high level, the costs are higher than necessary.

SPT2ARC-1227 - Furthermore, it has to be understood that there is a shared cost of ownership for the different parties: Infrastructure Managers, Operators, Suppliers, Transport Authorities, and Rolling Stock Leasing Companies (ROSCO) . Costs have to consider the whole product life cycle. Costs are related to the development phase and to the running phase including operation / maintenance but also obsolescence management / functionality upgrades.

SPT2ARC-1226 - Railways are looking for protection of investment that is stable over time (save investments for railways). This means that investments already made or future investments can be supported by the right degree of decomposition.

SPT2ARC-1259 - For suppliers too many interfaces and too small components are a cost driver for development and certification. Furthermore, suppliers have product roadmaps with investment plans. This has to be taken into account but can't be a "blocking issue". In addition, each new set of products to develop, increase the size of the portfolio to be maintained as the former systems do not disappear and have to be maintained as well (protect investments for suppliers). If additional requirements as for decomposition are introduced then additional investments are needed. If there are no new functionalities it is difficult to receive a return on investment . So, the increased level of decomposition has to be understood as enhancements by the sector. In the decomposition of the CCS system it could be an aspect to consider what will generate profit and also allow this to a reasonable extent. It is necessary to allow system vendors to have a health and duable profit.

SPT2ARC-1258 - Depending on the functional split and the related decompositions between trackside and on-board there are different costs for Infrastructure Management and Operation with potential effects on competition and openness of the market.

5.4 Conclusion for the problem statement

SPT2ARC-1257 - As it cannot be determined in advance where is the optimum between the level of granularity and CCS costs a step by step approach is needed for decomposition.

SPT2ARC-1255 - Simple rules for decomposition / granularity are needed which can guide the System Pillar Domains through the process.

SPT2ARC-1253 - Each step needs to be justified adequately to achieve the objectives of SERA . Part of the granularity decision should be a quantitative cost analysis.

SPT2ARC-1250 - In this document detailed principles/criteria for granularity shall be derived from CBO and from the architecture principles .

6 Granularization Objectives and Principles

SPT2ARC-1656 - In general the granularity principles are based on the following agreement from [SP-Ramp-up DP2.2] SPT2ARC-1657, section 5.9.2: “Basically, there can be separated between different basic design principles for subsystem architecture:

- Mandatory to achieve interoperability
- Mandatory for migration from intermediate migration targets towards the target architecture
- if a separation into subsystems is economically viable from railways and suppliers’ points of view".

SPT2ARC-955 - ERJU is working on the definition of the future CCS architecture. In the frame of the harmonisation of the ERTMS part of CCS, the harmonisation of the interoperability has been limited to the extent that trains equipped by one supplier can run on lines equipped by other suppliers. As the objectives of ERJU go beyond the interoperability goals of ERTMS, the CCS system shall be broken down into sub-systems. It is assumed that such a breakdown into smaller, interoperable units shall contribute to the goals of increased overall performance, economic viability (from railways and suppliers’ points of view), migration and innovation. The term granularization has been used for this step. Several initiatives, such as Eulynx, RCA, OCORA and several work packages in the Innovation Pillar of the ERJU, already exist, where such work has been started. To decide, to which level the granularization shall be extended objectives need to be defined and their achievement to be evaluated. Where a further level of granularization cannot be justified by contributing to the goals of ERJU or is even hampering the achievement of these goals, the granularization shall stop.

General aspects

Some general aspects however apply to the topic of granularization, regardless of the objectives:

SPT2ARC-954 -

- An architecture with a suitable level of granularisation can reduce the Total Cost of Ownership (TCO) of systems for the IMs and RUs . However, as the minimum of the TCO-over-granularity function is not known beforehand, an approximation by evaluating architecture candidates against granularisation criteria is strictly necessary (total cost of ownership reduction over effort required for harmonisation, testing and system integration, considering also volumes, long term evolution etc.).

SPT2ARC-952 -

- With each additional level of granularization the effort for harmonisation increases. Note that it is not only necessary to specify requirements, interfaces, and functions, but also PRAMSS requirements, test specifications etc., which are all relevant for development and certification.

SPT2ARC-950 -

- Depending on whether interoperability, exchangeability or interchangeability shall be achieved, many more aspects of a sub-system need to be specified, such as engineering rules, connectors, mechanical characteristics, power supply requirements, cooling requirements etc.

SPT2ARC-948 -

- With each additional level of granularization changes in one sub-system might require changes in one or multiple other sub-systems. A good level of granularization is reached if such interfaces can be defined to avoid this problem as far as possible. These changes need to be implemented at the same time, as upward and downward compatibility at each additional interface will result in an

increased level of complexity. Example: If we add a location function which calculates and displays a new position value on the DMI today we need to change the SRS of ETCS and the DMI FFFIS. In a more granular system we might have to change also the ASTP interface to the EVC, the EVC to the DMI interface and the ASTP and DMI SRSs, as well as the corresponding test specifications, various RAMS documents, etc. and each of these subsystems will have to go through interoperability testing and be individually certified.

SPT2ARC-946 -

- As signalling systems typically have a long lifespan, benefits expected from additional granularization for future replacement might not materialise as harmonised interfaces also have a limited lifespan. Note: Subsystems of the signalling systems have a different lifespan resulting in partial renewal over the total lifespan. Possible mitigations can be to have adaptable interfaces and to avoid downwards incompatibilities.

SPT2ARC-944 - To guide the process of evaluating the advantages and disadvantage of increased granularization, the objectives of any granularization must be defined. Expected benefits from each level of granularization shall be listed and quantified, and all conditions listed which have to be met to achieve the expected benefits. In this process the above-mentioned general aspects shall be considered, too.

SPT2ARC-1315 - The following sections contain several already identified objectives with their goals, justification, conditions, etc. Examples have also been added for interfaces, where the respective sub-systems and interfaces have been defined to achieve the respective objective.

6.1 Objective: Interoperability for cross border operation / open network access

SPT2ARC-942 -

Objective	Goal	Justification	Condition	Risks	Examples (onboard and trackside)
Interoperability for cross border operation / open network access	Trains can run on one single European railway area.	Interoperability, reduction or elimination of national systems required on trains	Relevant interfaces need to be fully harmonised (FFFIS), including RAMS, test specifications etc. as required for certification.	Changes to harmonised functions or interfaces need to be agreed across the sector, implementation and rollout take time.	Complete ETCS onboard system, complete trackside signalling system

6.1.1 Derived Granularity Principles

SPT2ARC-968 - Interfaces relevant for interoperability need to be identified and defined on FFFIS level.

SPT2ARC-1027 - Trains with equipment from one supplier can run on lines with equipment from other suppliers.

6.2 Objective: Cost reduction at the LCC level

SPT2ARC-941 -

Objective	Goal	Justification	Condition	Risks	Examples (onboard and trackside)
Cost reduction at the LCC level	The costs of CCS systems shall be reduced.	Competitiveness of rail versus other modes of transport.	Only relevant and harmonised requirements (overspecification avoided) are the key to cost reductions . Harmonised sub-systems usable in the complete EU market (SERA) with higher number of pieces.	Potential gains across the complete railway system might not be fully considered. Expected scale effects might not be achieved due to customer specific requirements impacting operating rules or interoperability or national requirements.	Open point: To be done in the economic assessment on granularity

6.2.1 Derived Granularity Principles

SPT2ARC-964 - Reduced customer specific requirements but harmonised requirements and eliminate national add-ons.

SPT2ARC-967 - Harmonised interfaces for integration in boundary system.

SPT2ARC-966 - Defined sub-systems with manageable complexity.

SPT2ARC-962 - Avoid unnecessary complex interfaces. The complexity of an interface is characterised by the effort to specify it, to design/implement/configure/integrate it and/or to validate it.

SPT2ARC-961 - Avoid a too complex integration. Acomplex integration is characterised as an integration that needs large efforts for implementing the interface on both side and validate it.

SPT2ARC-963 - Defined sub-systems including harmonised interfaces only in case there is a market (maybe also a new markets) with volumes justifying the harmonisation effort. Note: What exactly are large volumes has to be decided case by case by the experts of the respective domains.

SPT2ARC-1293 - Defined sub-systems including harmonised interfaces in case it has to be integrated / interfaced with another part which has a totally different life-cycle, e.g.: interface to the FRMCS Radio.

SPT2ARC-1290 - If there is a solution which is proven in use (proven maturity) is has to be taken into account in the system analysis.

SPT2ARC-1291 - Wherever possible, reusing solutions that have proven their maturity is one key to cost reductions.

SPT2ARC-1292 - Reduce interfaces between safety relevant subsystems: If possible, safety relevant functions should not be spread over different subsystems as these interfaces always needs to be thoroughly tested and integrated with all possible combinations (note that it is not excluded by this principle to have cases in which it is done as e.g. for ETCS on-board, Absolute Safe Train Positioning, Automatic Processing Module for GoA3/4 etc.).

6.3 Objective: Creating open markets for sub-systems and ensure competition

SPT2ARC-958 -

Objective	Goal	Justification	Condition	Risks	Examples (onboard and trackside)
Creating open markets for sub-systems and ensure competition	Harmonised interfaces and functionalities shall help to create open markets for sub-systems, in which they can be combined to build interoperable onboard or trackside system with limited or no need for	Economical; better business case for new subsystems	The overall set of specification including additional interfaces need to be fully harmonised (FFFIS) , including RAMS, test specification etc. as required for	Cost reduction can only come from larger volumes per supplier. Also non-harmonised sub-systems are still available, which makes it questionable whether the newer alternatives will be bought. Sub-systems	Separation of DMI, vehicle adapter, radio, STMs or enhanced train positioning system from ETCS onboard system. Separation of field element object controllers from interlocking core. RBC-RBC-interface. Interfaces between operation control systems/traffic management systems

	additional certification.		certification.	with additional harmonised interfaces are more costly to harmonise, develop, certify, and also to produce.	and interlockings. Using products or standards from other large industry markets as Lidar from automotive and standard radio systems.

6.3.1 Derived Granularity Principles

SPT2ARC-985 - See SPT2ARC-963 - Defined sub-systems including harmonised interfaces only in case there is a mark...

6.4 Objective: Create broader supplier base

SPT2ARC-957 -

Objective	Goal	Justification	Condition	Risks	Examples (onboard and trackside)
Create broader supplier base	Make more resources available to increase speed of implementation of systems / support faster rollout	Accelerate implementation of SERA / deployment of ERTMS	Larger volumes are required to increase number of suppliers, conditions must be attractive to suppliers	Established suppliers might leave the market, new suppliers won't stay	GSM-R has never been attractive to outsiders despite the open interfaces

6.4.1 Derived Granularity Principles

SPT2ARC-987 - Reduce or eliminate railway specific requirements (e.g. temperature requirements with -40°C which never achieved on modern train vehicles).

SPT2ARC-1294 - See SPT2ARC-963 - Defined sub-systems including harmonised interfaces only in case there is a mark...

SPT2ARC-974 - It should be avoided to decompose sub-systems for already established sub-systems retrospectively unless is is clearly justified by a business case. Example: The ETCS on-board should not be

decomposed with the exception in case of major enhancements as ASTP or new major features for which new sub-systems is reasonable .

SPT2ARC-972 - It should be avoided to re-define already established / harmonised interfaces (e.g. RBC – ETCS on-board).

6.5 Objective: Support integration of new systems into existing environments

SPT2ARC-956 -

Objective	Goal	Justification	Condition	Risks	Examples (onboard and trackside)
Support integration of new systems into existing environments	Simplify the integration of products into existing or new environments through harmonised interfaces	Costs and duration of projects	Existing environments need to support the relevant interfaces.	The existing environment and its systems don't support newly harmonised interfaces, so they might have to be upgraded first before the benefits can be achieved. If the new interfaces are only applied to new installations, then then this can be an obstacle for the rollout.	Vehicle adapter for existing rolling stock, as well as train interface for new rolling stock, both resulting in a harmonised interface between rolling stock and ETCS

6.5.1 Derived Granularity Principles

SPT2ARC-978 - See SPT2ARC-967 - Harmonised interfaces for integration in boundary system.

SPT2ARC-977 - Upgrade environment to provide the harmonised interface (including e.g. safety level).

SPT2ARC-981 - Harmonisation on non-interchangeable level which include reasonable options and supplier specific application conditions and are defined to ease integration.

SPT2ARC-979 - Harmonisation on FIS level if too many options and supplier specific application conditions cannot be avoided or no harmonisation at all in this case.

SPT2ARC-1295 - Design intermediate adaptors between an existing sub-system and a new interface.

6.6 Objective: Support Migration

SPT2ARC-953 -

Objective	Goal	Justification	Condition	Risks	Examples (onboard and trackside)
Support Migration	Simplify the migration to the European CCS through harmonised interfaces	Cost and duration of migration	Existing environments need to support the relevant interfaces.	The existing environment and its systems don't support newly harmonised interfaces, so they might have to be upgraded first before the benefits can be achieved. If the new interfaces are only applied to new installations, then this can be an obstacle for the rollout.	STM-Interface

6.6.1 Derived Granularity Principles

SPT2ARC-975 - Sub-systems / interfaces are defined in multiple steps . A cost / benefit analysis has proven that intermediate steps of the evolution are the best option for the migration.

SPT2ARC-1299 - The impact a new sub-system could have on the interfaces, engineering efforts and integration, certifications should be analysed using case studies so as to respond to the CBO related objectives.

SPT2ARC-1297 - See SPT2ARC-1295 - Design intermediate adaptors between an existing sub-system and a new interface.

6.7 Objective: Long term sustainment of the service

SPT2ARC-951 -

Objective	Goal	Justification	Condition	Risks	Examples (onboard and trackside)

Long term sustainment of the service	Support sustaining service over long time periods despite using sub-systems of different lifespans	Obsolescence management	Future environments need to support the relevant interfaces.	Due to the long lifespan of many systems in the rail business it is questionable whether many of the newly planned interfaces will ever be rolled out over significant parts of the system	Different lifespans of trackside assets and interlockings. In general, the clear separation between hardware and software.

6.7.1 Derived Granularity Principles

SPT2ARC-973 - Identify and separate sub-systems with different lifespans.

SPT2ARC-971 - Identify and separate sub-systems only if there can be stable long-term interfaces and functionalities available.

6.8 Objective: Manage different lifecycles of systems

SPT2ARC-949 -

Objective	Goal	Justification	Condition	Risks	Examples (onboard and trackside)
Manage different lifecycles of systems	To replace sub-systems with no impact on other parts of the system	No changes to remaining system when replacing some systems.	Interfaces need to remain unchanged, no increase of functionalities.	Differences in replacement products might anyway require changes to remaining systems.	IXL connected to field elements (e.g. the point machine may have another lifecycle than the IXL)

6.8.1 Derived Granularity Principles

SPT2ARC-970 - Defined interfaces and updated sub-systems shall allow backwards compatibility to the other sub-systems

6.9 Objective: Interchangeability

SPT2ARC-947 -

Objective	Goal	Justification	Condition	Risks	Examples (onboard and trackside)
Interchangeability	To freely exchange sub-systems from different suppliers in already certified installations without a need for any form of certification or additional testing (plug and play).	Reduction of downtimes (reduction of MTTR) as spare parts are not needed to come from one specific supplier.	Apart from the relevant interfaces, many additional product characteristics need to be harmonised. This includes all mechanical and electrical characteristics, installation conditions, etc. No supplier specific application conditions are permitted. At least with a prototype safety has to be demonstrated for all possible combinations of subsystems. This may only be achieved, if the installation was approved (at least the prototype) AND the subsystem was approved (i.e. type approval based on GPSC or GASC) AND the sub-system fulfils the requirements needed by the installation (see ERJU PRAMS Plan for a possible solution).	Apart from the object controllers of the SSI interlocking, no other example exists where such a level of harmonisation has been achieved in safety critical systems.	Object controllers of the SSI interlocking

6.9.1 Derived Granularity Principles

SPT2ARC-969 - FFFIS requires that all relevant characteristics of a sub-system are covered (e.g. for interchangeability all mechanical, electrical, environmental and functional characteristics can be harmonised).

SPT2ARC-984 - Interchangeable sub-systems should not include any customer specific additions.

SPT2ARC-983 - FFFIS shall not change over time. In case of a FFFIS evolution a FFFIS shall remain backwards compatible.

6.10 Objective: Exchangeability

SPT2ARC-1632 -

Objective	Goal	Justification	Condition	Risks	Examples (onboard and trackside)
Exchangeability	To ease integration; exchange sub-systems from different suppliers with only a reasonable integration and/or certification effort.	Reduction of integration and certification costs with harmonised functionality,data interfaces and safety requirements.	Apart from the relevant interfaces, many additional product characteristics need to be harmonised. This includes electrical characteristics, installation conditions, safety and security requirements etc.	The existing sub-systems do not support newly harmonised interfaces, so they might have to be upgraded first before the benefits can be achieved. If the new interfaces are only applied to new installations, then then this can be an obstacle for the rollout.	FFFIS Train Interfaces Subset-119 or FFFIS between ATO on-board and ETCS on-board Subset-130

6.10.1 Derived Granularity Principles

SPT2ARC-1628 - FFFIS requires that the relevant characteristics of a sub-system are covered to facilitate integration (e.g. for exchangeability electrical and functional characteristics, safety, security, and performance requirements should be harmonised).

SPT2ARC-1631 - SPT2ARC-984 - Interchangeable sub-systems should not include any customer specific additions.

SPT2ARC-1629 - SPT2ARC-983 - FFFIS shall not change over time. In case of a FFFIS evolution a FFFIS shall rem...

6.11 Objective: Independent changeability for non-safe and safe sub-systems

SPT2ARC-945 -

Objective	Goal	Justification	Condition	Risks	Examples (onboard and trackside)
Independent changeability for non-safe and safe sub-systems	If decomposition separates components that contain safety critical functions from components that contain on only non-safety critical functions no authorisation is needed for the non-safety critical parts. Non-safety critical parts can be updated independently or more frequently. Designs can be simpler for non-safe systems and changes less costly.	Economical, maintainability	Different safety requirements between sub-systems	Normally, TSI driven updates are impacting both safe and non-safe functions, which are also interacting, so the expected benefits might not be materialised. No benefit due to the authorisation processes.	Euroradio Gateway for the communication layers while the safety layer is in the ETCS onboard system; more frequent update for security patches on a non-safety critical sub-system.

6.11.1 Derived Granularity Principles

SPT2ARC-982 - Separate sub-systems for which different SIL can be defined.

6.12 Objective: Different Performance or RAM requirements of sub-systems

SPT2ARC-943 -

Objective	Goal	Justification	Condition	Risks	Examples (onboard and trackside)
Different Performance or RAM requirements of sub-systems	Decomposition separates functions with different performance or availability requirements so that sub-systems with low performance or availability requirements are less costly.	Economical	Different RAM or performance requirements between sub-systems		On-board Recording Device (Juridical Recorder). Diagnostic systems and core safety systems, e.g. point diagnostics separated form point control.

6.12.1 Derived Granularity Principles

SPT2ARC-980 - Separate sub-systems for which different Performance or RAM can be defined.

6.13 Objective: Independent changeability of shared functionality

SPT2ARC-959 -

Objective	Goal	Justification	Condition	Risks	Examples (onboard and trackside)
Independent changeability of shared functionality	A sub-system provides functions for different sub-systems. The sub-system might need to be changed due to new requirements from one sub-system to	Economical	Functions are shared by different sub-systems	Changes required in a shared function by one sub-system might impact other sub-systems and interfaces. Normally, TSI driven updates are impacting	The existing odometry function, currently part of the ETCS on-board, is proposed to be made independent by creating the new ASTP sub-system.

	which the functionality is provided but other sub-systems do not need a change.			both shared functions and non-shared functions, which are also interacting, so the expected benefits might not be materialised.	

6.13.1 Derived Granularity Principles

SPT2ARC-976 - Separate a sub-system which contains functions which can be shared by different other sub-systems. The sub-system might need to be changed due to new requirements from one sub-system to which the functionality is provided but other sub-systems do not need a change.

6.14 Objective: Maintain and upgrade legacy systems not supported by the original supplier

SPT2ARC-1028 -

Objective	Goal	Justification	Condition	Risks	Examples (onboard and trackside)
Maintain and upgrade legacy systems not supported by the original supplier	To ease the replacement of a sub-system by one of another supplier which includes obsolescence and additional functionality.	Economical	Harmonised Interfaces have not changed.	Due to changes of technology, new modules don't match the legacy interface.	DMI which have short life cycles and need new design because of lack of spare parts.

6.14.1 Derived Granularity Principles

SPT2ARC-1030 - See SPT2ARC-973 - Identify and separate sub-systems with different lifespans.

SPT2ARC-1029 - See SPT2ARC-971 - Identify and separate sub-systems only if there can be stable long-term interfac...

7 Decomposition rules

7.1 Introduction

For the architecture principles: see [ARC-Guidelines] SPT2ARC-1653 ARC-D2.5 Architecture Guidelines.

These granularity rules should be commonly applied on System/Sub-system Architecture / Physical Architecture level, which is the lowest level where "real" sub-systems and interfaces will be designed but should be also considered at earlier steps of the modelling process. These rules should be used to determine where to cut a sub-system out of the entire system and what functions need to go into it.

7.2 Granularity rules

SPT2ARC-1655 - *This paragraph contains a list of rules for specifying the right balance of granularity. These rules shall be a guideline for the SP Domains involved in architecture design to make granularity choices and architecture decisions.*

SPT2ARC-1283 -

Rule title	Rule description	Expected benefits	Related objectives (including benefits and risks) / related principles
Interface only with justifiable data	Sub-systems should have justified, well defined interfaces.	All benefits of section SPT2ARC-862 - Benefits of decomposition	All objectives can be supported with this rule, especially SPT2ARC-942 / SPT2ARC-968; SPT2ARC-1027 and SPT2ARC-947 / SPT2ARC-969; SPT2ARC-984 and

			SPT2ARC-1632 / SPT2ARC-1628 ; SPT2ARC-984 and SPT2ARC-945 / SPT2ARC-982 and SPT2ARC-943 / SPT2ARC-980 and SPT2ARC-956 / SPT2ARC-967; SPT2ARC-977; SPT2ARC-981

SPT2ARC-1282 -

Rule title	Rule description	Expected benefits	Related objectives (including benefits and risks) / related principles
Avoid mixing functions of different quality attributes	The system architecture should aim for a strict separation of functions with different quality attributes (safety, RAM, performance).	Since the function requiring the highest quality attribute defines the quality required of all other functions in the same sub-system. Mixing of functions requiring different quality attributes in one sub-system should be avoided.	SPT2ARC-945 / SPT2ARC-982 and SPT2ARC-943 / SPT2ARC-980

SPT2ARC-1279 -

Rule title	Rule description	Expected benefits	Related objectives (including benefits and risks) / related principles
Isolate optional functions	Functionalities not needed in all CCS implementations should be isolated into separated sub-systems	To allow deployment of functionality on a needed basis. Risks: • The rule could provoke a high number of sub-systems. That means also a really big number of interfaces to define. Also a really big number of interfaces could have a negative impact in the system performance. • The rule can be misused and might lead to the contrary. An optional sub-function of a sub-system candidate would immediately lead to two sub-systems. The original one with a "hole" in it containing a new island sub-system with the optional functionality. Instead, the optional functionality could either be avoided or configured.	SPT2ARC-953 / SPT2ARC-975 and SPT2ARC-956 / SPT2ARC-979; SPT2ARC-981

SPT2ARC-1278 -

Rule title	Rule description	Expected benefits	Related objectives (including benefits and risks) / related principles
Ensure coherent and consistent life-cycles	Functional decomposition and functional allocation should ensure coherent and consistent sub-system life-cycles. It includes to identify and separate sub-systems with different lifespans in case there can be stable long-term interfaces and functionalities.	This is to achieve an independent life-cycle management for each of the sub-systems. This concerns especially CCS functions which are identified as likely to evolve in the future or which have often evolved during the previous baselines (e.g. ATO, localisation, CR about re-localisation (CR782, CR1370), braking curves).	SPT2ARC-949 / SPT2ARC-970 and SPT2ARC-951 / SPT2ARC-973; SPT2ARC-971 and SPT2ARC-1028 / SPT2ARC-973; SPT2ARC-971 and SPT2ARC-941 / SPT2ARC-1293

SPT2ARC-1276 -

Rule title	Rule description	Expected benefits	Related objectives (including benefits and risks) / related principles
Aim at realizing functions in software	The architecture should aim at realising functions in software (applications and services) and avoid binding them to a specific hardware. *Remark: The applicability and possible restrictions of this rule depends on the results of the Computing Environment Domain.*	To maximize reuse. To protect investments. To improve expandability. To facilitate innovation.	SPT2ARC-941/ SPT2ARC-966

SPT2ARC-1275 -

Rule title	Rule description	Expected benefits	Related objectives (including benefits and risks) / related principles
Aim for balanced integration effort	The architecture should aim at a balanced relation between modularity and integration efforts.	To ensure that modularity benefits are not sacrificed by exponential integration effort, see SPT2ARC-1240 - Less complex sub-systems ; SPT2ARC-1239 - Simplification of system integration.	SPT2ARC-941 / SPT2ARC-966; SPT2ARC-962; SPT2ARC-961 and SPT2ARC-947 / SPT2ARC-969; SPT2ARC-984 and SPT2ARC-953 / SPT2ARC-1299

SPT2ARC-1270 -

Rule title	Rule description	Expected benefits	Related objectives (including benefits and risks) / related principles
Aim for balanced certification effort	The architecture should aim at a balanced relation between modularity and certification effort.	To ensure that modularity benefits are not sacrificed by exponential integration effort, see SPT2ARC-1240 - Less complex sub-systems ; SPT2ARC-1239 - Simplification of system integration.	SPT2ARC-941/ SPT2ARC-966; SPT2ARC-962; SPT2ARC-961; SPT2ARC-963 and SPT2ARC-947 / SPT2ARC-969; SPT2ARC-984 and SPT2ARC-958 / SPT2ARC-963 and SPT2ARC-953

			/ SPT2ARC-1299

SPT2ARC-1271 -

Rule title	Rule description	Expected benefits	Related objectives (including benefits and risks) / related principles
Aim for balanced maintenance effort	The architecture should aim at a balanced relation between modularity and maintenance effort.	Ensures that modularity benefits are not sacrificed by exponential maintenance effort; SPT2ARC-1241 - Benefits for adaptability, changeability, updateability and upgradeability ; SPT2ARC-1231 - Benefits for maintainability	SPT2ARC-941 / SPT2ARC-966; SPT2ARC-962; SPT2ARC-961 and SPT2ARC-947 / SPT2ARC-969; SPT2ARC-984

SPT2ARC-1272 -

Rule title	Rule description	Expected benefits	Related objectives (including benefits and risks) / related principles

Aim for a strict separation of hardware and software	Whenever reasonably possible, the system architecture should aim to strictly separate hardware and software (business logic). *Remark: The applicability and possible restrictions of this rule depends on the results of the Computing Environment Domain.*	To be able to handle the very different life-cycles. To protect the investment of developed software. To maintain software quality across different hardware generations.	SPT2ARC-951 / SPT2ARC-973; SPT2ARC-971

SPT2ARC-1281 -

Rule title	Rule description	Expected benefits	Related objectives (including benefits and risks) / related principles
Effort of changing products only for harmonisation	In the evaluation of advantages and efforts it has to be considered also the initial effort of changing products only for harmonisation.	Protect investments which have been made already. Avoid obstacles for the introduction of new sub-systems in the market and ERTMS deployment.	SPT2ARC-957 / SPT2ARC-974; SPT2ARC-972

SPT2ARC-1280 -

Rule title	Rule description	Expected benefits	Related objectives (including benefits and risks) / related principles

Evolution vs. stability of interfaces	Harmonised interfaces need to be stable. Possible evolutions have to be considered in a roadmap. For stability and backwards compatibility is needed. Defined interfaces and updated sub-systems shall allow backwards compatibility to the other sub-systems.	Protect investments; SPT2ARC-1241 - Benefits for adaptability, changeability, updateability and upgradeability ; SPT2ARC-1256 - Benefits for evolvability; SPT2ARC-1254 - Benefits for scalability; SPT2ARC-1256 - Benefits for evolvability	SPT2ARC-957 / SPT2ARC-974; SPT2ARC-972 and SPT2ARC-1028 / SPT2ARC-971 and SPT2ARC-949 / SPT2ARC-970 and SPT2ARC-947 / SPT2ARC-983 and SPT2ARC-1632 / SPT2ARC-983

SPT2ARC-1274 -

Rule title	Rule description	Expected benefits	Related objectives (including benefits and risks) / related principles
Consider current granularity specifications	Consider the granularity as currently specified in the TSI CCS and its SUBSETS. Many SUBSETS (especially on the CCS On-Board) are already requesting a certain granularity (e.g. Subset-119, Subset-147, Subset-130, etc.) that need to be considered when defining the right balance of granularity.	A lot of work has already been put into the SUBSET specifications. Some of the SUBSETS are already well advanced and proven, while others may still need some work. By considering all the existing SUBSETS when defining granularity, a lot of (re-)work can be avoided and already existing solutions can be re-used (protecting the investments).	SPT2ARC-957 / SPT2ARC-974; SPT2ARC-972

SPT2ARC-1273 -

Rule title	Rule description	Expected benefits	Related objectives (including benefits and risks) / related principles
New major enhancements as separate sub-system	Whenever possible and reasonable, new functionalities of major enhancements (e.g. ASTP, ATO GoA 3/4, etc.) should be isolated in a new subsystem.	Independent upgradeability and evolution of the different functionalities	SPT2ARC-957 / SPT2ARC-974

SPT2ARC-1603 -

Rule title	Rule description	Expected benefits	Related objectives (including benefits and risks) / related principles
Avoidance to decompose sub-systems for already established sub-systems retrospectively	It should be avoided to decompose sub-systems for already established sub-systems retrospectively unless is clearly justified by a business case. Example: The ETCS on-board should not be decomposed with the exception in case of major enhancements as ASTP or new major features for which new sub-systems is reasonable.	Protect investments which have been made already. Avoid unneeded costs and delays for CCS/ERTMS deployment.	SPT2ARC-957 / SPT2ARC-974

SPT2ARC-1277 -

Rule title	Rule description	Expected benefits	Related objectives (including benefits and risks) / related principles

Critical mass of a sub-system	One single sub-system should not be smaller than a critical mass, in terms of: market volumes, functional grouping, overhead costs (e.g. mechanical housing, logistics, etc.)	Avoid unneeded and a too high number of sub-systems. New sub-systems including harmonised interfaces should be defined only in case there is a market (maybe also a new markets) with volumes justifying the harmonisation effort. See SPT2ARC-1252.	SPT2ARC-958 / SPT2ARC-963 and SPT2ARC-957/ SPT2ARC-963 and SPT2ARC-941 / SPT2ARC-963

SPT2ARC-1289 -

Rule title	Rule description	Expected benefits	Related objectives (including benefits and risks) / related principles
Evaluation to use parametrisation	Evaluation and definition of what is 'hard coded' in hardware / software (business logic) and what shall be defined by means of parametrisation.	Without considering this rule parametrisation one ends with a large number of quite similar but slightly different sub-systems.	SPT2ARC-941 / SPT2ARC-964; SPT2ARC-962; SPT2ARC-961

SPT2ARC-1288 -

Rule title	Rule description	Expected benefits	Related objectives (including benefits and risks) / related principles

Avoidance of options	There should be no options in the harmonised architecture relevant for interoperability (e.g. Euroloop; not related to the interoperability is e.g. the option to have ATO or not).	In case of interoperability the complete interface should be harmonised. Standardised options which are used only in rarer cases create unneeded development costs.	SPT2ARC-941 / SPT2ARC-964; SPT2ARC-962; SPT2ARC-961 and SPT2ARC-956 / SPT2ARC-981

SPT2ARC-1287 -

Rule title	Rule description	Expected benefits	Related objectives (including benefits and risks) / related principles
Ontologies to define semantics	Ontologies should define the semantics of data exchange and expected behaviour of sub-systems.	This promotes interoperability and allows for integration of innovative solutions that conform to standard interfaces without FFFIS but FIS.	all ojectives can be supported with this rule, especially: SPT2ARC-956 / SPT2ARC-979

SPT2ARC-1607 -

Rule title	Rule description	Expected benefits	Related objectives (including benefits and risks) / related principles
Harmonisation for functional apportionment	Harmonisation on FIS level if too many options and supplier specific application conditions cannot be avoided or there should be no harmonisation at all in this case.	Integration of innovative solutions that conform to standard interfaces without FFFIS but FIS.	SPT2ARC-956 / SPT2ARC-979

SPT2ARC-1606 -

Rule title	Rule description	Expected benefits	Related objectives (including benefits and risks) / related principles
Independent changeability of interfaces	With each additional level of granularization, changes in one sub-system might require changes in one or multiple other sub-systems. A good level of granularization is reached if such interfaces can be defined to avoid this problem as far as possible.	SPT2ARC-1231 - Benefits for maintainability; SPT2ARC-1241 - Benefits for adaptability, changeability, updateability and upgradeability	all objectives can be supported with this rule

SPT2ARC-1605 -

Rule title	Rule description	Expected benefits	Related objectives (including benefits and risks) / related principles
Decomposition only if linked to a harmonisation level	Harmonised design choices for decomposition which are not needed for interchangeability, exchangeability, interoperability, safety or functional apportionment shall be avoided. Design choices for decomposition in this case can be also supplier specific.	Avoid harmonised decomposition without benefit for harmonisation (for on of the levels of harmonisation).	all objectives can be supported with this rule, especially SPT2ARC-942 / SPT2ARC-968; SPT2ARC-1027 and SPT2ARC-947 / SPT2ARC-969; SPT2ARC-984 and SPT2ARC-945 / SPT2ARC-982 and SPT2ARC-943

			/ SPT2ARC-980

SPT2ARC-1593 -

Rule title	Rule description	Expected benefits	Related objectives (including benefits and risks) / related principles
Avoidance of SRACS	There should be no SRACs (Safety-related Application Conditions) between harmonised sub-system of the same architecture level. By the top down approach with safety requirements these SRACs can be avoided.	Certification and authorisation could be more complex if by the creation of sub-systems a high dependency and interrelation between the subsystems is created.	all objectives can be supported with this rule

SPT2ARC-1594 -

Rule title	Rule description	Expected benefits	Related objectives (including benefits and risks) / related principles
Separation of shared functionality	In case of functions are shared by different sub-systems, the sub-system which contains these functions should be separated.	The sub-system might need to be changed due to new requirements from one sub-system to which the functionality is provided but other sub-systems do not need a change.	SPT2ARC-959 / SPT2ARC-976

SPT2ARC-1595 -

Rule title	Rule description	Expected benefits	Related objectives (including benefits and risks) / related principles
Consideration of proven in use solutions	If there is a solution which is proven in use (proven maturity) this has to be taken into account in the system analysis	Support for achieving a mature solution. Wherever possible, reusing solutions that have proven their maturity is one key to cost reductions.	SPT2ARC-941 / SPT2ARC-1290; SPT2ARC-1291

SPT2ARC-1598 -

Rule title	Rule description	Expected benefits	Related objectives (including benefits and risks) / related principles
Reduce railway specific requirements	For the definition of new sub-systems or interfaces reduce or eliminate railway specific requirements (e.g. temperature requirements with -40°C which never achieved on modern train vehicles).	Create broader supplier base; support faster rollout	SPT2ARC-957 / SPT2ARC-987

SPT2ARC-1597 -

Rule title	Rule description	Expected benefits	Related objectives (including benefits and risks) / related principles

Reduce interfaces between safety relevant subsystems	If possible, safety relevant functions should not be spread over different subsystems.	Interfaces of safe sub-systems always needs to be thoroughly tested and integrated with all possible combinations (note that it is not excluded by this principle to have cases in which it is done as e.g. for ETCS on-board, Absolute Safe Train Positioning, Automatic Processing Module for GoA3/4 etc.).	SPT2ARC-941 / SPT2ARC-1292 and SPT2ARC-945 / SPT2ARC-982

SPT2ARC-1599 -

Rule title	Rule description	Expected benefits	Related objectives (including benefits and risks) / related principles
Adapt the environment or existing sub-systems for newly defined interfaces	Envisage the preparation of the environment or existing sub-systems for newly defined interfaces (including e.g. safety level).	Faster integration of new sub-systems / new interfaces; cost and effort reduction for deployment.	SPT2ARC-956 / SPT2ARC-1295; SPT2ARC-977

SPT2ARC-1602 -

Rule title	Rule description	Expected benefits	Related objectives (including benefits and risks) / related principles

Harmonised requirements	For a new sub-system and its interfaces customer specific requirements shall be avoided. National add-ons shall be eliminated.	Having only relevant and harmonised requirements (overspecifying is avoided) is key to cost reductions.	SPT2ARC-941 / SPT2ARC-964 and SPT2ARC-947 / SPT2ARC-984

SPT2ARC-1627 -

Rule title	Rule description	Expected benefits	Related objectives (including benefits and risks) / related principles
Intermediate step for migration	Due to a cost / benefit analysis it is proven that the introduction of a sub-system / interfaces in an intermediate step of the evolution is the best option for the migration.	Intermediate step which enables migration to the railway or CCS target system; SPT2ARC-1234 - Benefits for migration	SPT2ARC-953 / SPT2ARC-975; SPT2ARC-1299

SPT2ARC-1626 -

Rule title	Rule description	Expected benefits	Related objectives (including benefits and risks) / related principles
Common ontology for data element in a domain architecture	All data elements in a domain architecture should use a common semantic dictionary, i.e. all data elements should be defined in a common ontology.	Mitigation for the risk SPT2ARC-1246 - Complexity of integration on customer level	SPT2ARC-947 / SPT2ARC-969 and SPT2ARC-942 / SPT2ARC-968

8 Open Issues

8.1 Effect of independent software functions on granularity

Software needs to run in an environment, i.e. Hardware, Operating System (OS), API to services provided by OS or other common Software, cyber security, safety case and Safety Related Application Conditions have to be fulfilled. It is difficult to make Software function independent to all of that while it could in addition affect granularity of function to get a good business model. We have to wait for the results from Computing Environment Domain for final conclusions on this topic in this document, see also SPT2ARC-1272 and SPT2ARC-1276 .

8.2 Quantification of estimated risks and economic values

The support of decisions by means of a business model has to be added to the document.

9 References

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4. [SEMP - Annex B] System Pillar SEMP Annex B: Architecture Principles SEMP Annex B - Architectural principles

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6. [Subset-037] EuroRadio FIS - CS/PS Communication Function Module, Subset of Annex A of TSI CCS 2023

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8. [EN50126-1:2017] Railway Applications. The Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS) Generic RAMS Process, 2017-12-06.

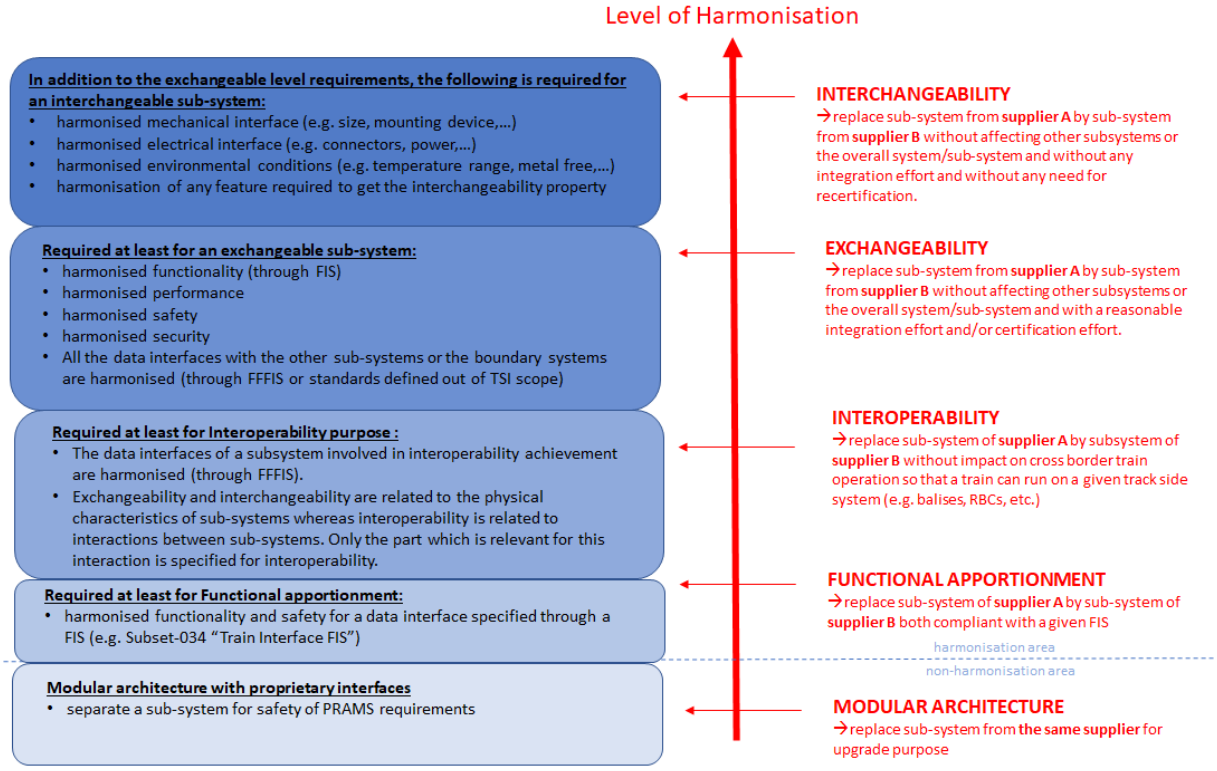
9. [SP-Report] Europe's Rail Joint Undertaking: System Pillar Report: Report on preparation of the System Pillar ("System Pillar Report").

10. [SP CBOs] ERJU, System Pillar: Common Business Objectives

11. [ARC-Guidelines] ERJU, System Pillar, ARC Domain: SPT2ARC-926 - ARC-D2.5 Architecture Guidelines

12. [SP-Ramp-up DP2.2], System-Pillar Ramp-up project: DP2.2 CCS and TMS System Architecture - Annex 1 CCS/TMS Architectural Principles

10 Figures and Tables



Appendix

11 Template for the Definition of new Sub-systems

In case of a new subsystem the following table shall be filled-in for all rules and objectives defined in this document. This ensures that the rules of chapter 7.2 SPT2ARC-428 - Granularity rules and objectives of chapter 6 SPT2ARC-422 - Granularization Objectives and Principles including the corresponding benefits and risks have been analysed.

Sub-system name	***name***
Rule or objective	*ID and Title*
• **Applicability**	*Yes or explanation in case of N/A*
• **Specific benefits**	*Explanation taking into account the rules benefits / objective goals and the general benefits in section SPT2ARC-862 - Benefits of decomposition*
• **Specific risks**	*Explanation taking into account the risks of objectives corresponding to the respective rule and the general risks in section SPT2ARC-859 - Risks of decomposition*
• **Remarks**	*Optional: Explanation of additional remarks and annotations*
...	...
Rule or objective	*ID and Title*
• **Applicability**	*Yes or explanation in case of N/A*
• **Specific benefits**	*Explanation taking into account the rules benefits / objective goals and the general benefits in section SPT2ARC-862 - Benefits of decomposition*
• **Specific risks**	*Explanation taking into account the risks of objectives corresponding to the respective rule and the general risks in section SPT2ARC-859 - Risks of decomposition*
• **Remarks**	*Optional: Explanation of additional remarks and annotations*
...	...
Conclusion for introducing a new subsystem	*Summary*
Conclusion for interducing new interfaces	*Summary including a clarification for the intended harmonisation level per interface*

12 System Pillar CBO related to Granularity

Source: See [SP CBOs] SPT2ARC-1654.

12.1 Prerequisites of CBO (§3.1 of CBO's)

SPT2ARC-564 - Railways are managing and operating the system with the responsibility to perfor ...
Railways are managing and operating the system with the responsibility to perform in a way that is matching the ambitious goals set by society and politics. Overall, it is the Railways that must deliver a competitive SERA with the help of the EC System Pillar. **Therefore, the Railways have the responsibility to ensure that the modules are updated and maintained over lifetime. Suppliers' contributions are vital to these ambitions** in developing and delivering high quality, competitive assets and services in Europe and beyond.

SPT2ARC-566 - The System Pillar will endeavour to simplify and **reduce the costs for the different stages** in deployment for the target system including authorisation procedures to ensure safety and security .

SPT2ARC-565 - Getting a performant system architecture right and providing the specifications **for interfaces and sub-systems (modules)** with high quality will be key, whilst paying attention to providing evolvable solutions.

12.2 Challenges (§3.2 Challenges of CBO's)

SPT2ARC-569 - High cost
Rail is currently often more expensive compared to other transport modes, in som ...
Rail is currently often more expensive compared to other transport modes, in some cases reflected on the intermediaries or passengers/users. To be more competitive and support future increased usage, rail must deliver more cost-efficient solutions and services compared to today.

12.3 Reduced Costs (§4.3 of CBO's)

SPT2ARC-568 - The ability to reduce total cost within the rail system is a precondition for railway business continuity in an intense intermodal competition.

SPT2ARC-567 -
Whole life cost matters - the pure purchase price of single asset components is normally not the main cost driver in a system, **(typically < 20 % of the life cycle cost), rather whole life costs must be considered.**

12.4 Reduce life cycle cost (§4.3.1 of CBO's)

SPT2ARC-572 - The system design shall implement features that allow an independence of lifecycles and compatibility as well as release steps on both sides of an interface ("connect old to new"). Technical obsolescence shall lead most often to "simple exchange" and reduced need for system test

SPT2ARC-571 - Ensure 'right first time' interoperability and delivery and mitigate the risk of debug and rework costs, including reusable safety cases, adequate documentation, knowledge and training dissemination, and incorporation of lessons learned

SPT2ARC-570 - Processes are oriented along an ever-changing system

12.5 Deliver affordable system updates (§4.3.2 of CBO's)

SPT2ARC-575 - Changeability and upgradeability shall ensure business continuity along the life-cycle with optimised investment scheme.

SPT2ARC-574 - The system design shall anticipate the need for updates at minimum effort as a driver to optimize the economic migration path towards future solutions

SPT2ARC-573 - Due to widely varying obsolescence timescales as typical for digital systems, an affordable life cycle cost and the capability to manage system integration of components, with clear objective of reasonable system updates of SW and digitalized system, is a crucial objective.

12.6 Produce solutions that are economically attractive (§4.3.3 of CBO's)

SPT2ARC-582 - Reduce the effort to plan, install, operate and use asset components through functional richness (e.g. configuration automation), automation, upwards and cross compatibility (dependencies limit lifespan), and on non-functional properties like robustness

SPT2ARC-581 - The economic viability has to consider the full lifecycle cost considering both Capex + Opex from railways and suppliers' points of view.

SPT2ARC-578 - Increase market size (cost efficiency and quality) for standardized solution and through regular update of standardized modular components.

12.7 Improve availability and reliability/robustness (§4.4.3 of CBO's)

SPT2ARC-577 - Rationalise trackside and onboard assets portfolio, as they are complex to maintain and diagnose, with many failure modes related to the harsh environment in which they are situated

12.8 Standardize Architecture (§4.5.2 of CBO's)

SPT2ARC-580 - Modularity
Achieving modularity, at the right level, that allows room for innovation "between interfaces", and that, at the same time, **reduces costs, by not reassessing the whole system when a module is changed or updated**.

SPT2ARC-1269 - Standardized architecture Harmonising this system architecture approach at European level, including standardization of interfaces, communications and data exchange.

SPT2ARC-1268 - Overall CAPEX/OPEX optimisation Achieving an efficient granularity of the architecture and the best way how to exploit the content (e.g. TSIs, standards, guidelines)

SPT2ARC-1265 - Robust, comprehensible, sustainable framework The standardised architecture must rely on robust, comprehensive and sustainable architecture framework.

12.9 Optimize safety strategies and standards (§4.5.4 of CBO's)

SPT2ARC-579 - Safety critical elements of a system should be optimized and simplified through ...
Safety critical elements of a system should be optimized and simplified through design by moving away from bespoke solutions. The development of these parameters facilitates a common approach to safety and security

SPT2ARC-576 - The exchange of components or connection of new sub-systems under production shall happen without a new safety case or preparation processes

12.10 Reduce the system complexity by optimal design to ease regulatory compliance (§4.6.2 of CBO's)

SPT2ARC-590 - Develop systems which allow clear and simple tender procedures

SPT2ARC-584 - Creating the conditions to limit terms & condition complexity, reuse contract standards and provide room for innovation

SPT2ARC-583 - Simplify not only the complexity and certification of products but also impacts on the general supply chain including services like planning, engineering, installation, commissioning, and maintenance

12.11 Fast migration and Rollout (§4.6.3 of CBO's)

SPT2ARC-589 - Incremental deployments that increase complexity and costs, need to be replaced by an efficient and coordinated migration strategy, based on adaptable systems.

SPT2ARC-586 - Generic solutions for simple repeatable design, testing and commissioning reducing deployment times, reducing project delivery costs and getting solutions to the customer sooner.

SPT2ARC-585 - Development of viable migration paths for all stakeholders from current systems to support the delivery of the target system and architecture.

SPT2ARC-588 - Protecting investments through backwards and forwards compatibility where technically feasible and economically viable for railways(RU, IM suppliers, and also customers (end-users) and investors

SPT2ARC-587 - Improving time to market.

12.12 Achieve overall comprehensive assessment (features, Capex, Opex, I&C etc.) of solutions (§4.6.4 of CBO's)

SPT2ARC-595 - Avoiding Capex bias when assessing Total cost of Ownership (CAPEX+OPEX) created by the architecture {overall CAPEX/OPEX optimisation}

SPT2ARC-594 - Achieving the capability for the operator (RU or IM) to make use of all pertinent information allowing the system to be operated properly and evolved throughout its life-cycle.

12.13 Improved EU Rail supply industry competitiveness (§4.7 in CBO's)

SPT2ARC-592 - Create and foster **standardized know-how** to secure support throughout the lifecycle

12.14 Make future railway system attractive for different actors inside and outside Europe (§4.7.1 of CBO's)

SPT2ARC-591 - efficient normative framework
Strengthening and streamlining a common, efficient, systematically coherent and simplified but rigorous binding **normative framework across the EU**. {efficient normative framework}

SPT2ARC-593 - "full" reusability
"Full" reusability of all types of products and artefacts which simplifies considerably current bureaucratic steps (prove once, cross-references, describe once, just reference, a request for authorisation could theoretically be a "one-pager" with references. Etc.). {full reusability}

12.15 Leverage on European rail technical expertise for other regional areas (§4.7.2 of CBO's)

SPT2ARC-596 - standardized architecture(2)
Guarantee the compatibility of sub-systems and components e.g. with the aid of standardized interfaces.