ECSS-Q-HB-80-04A
30 March 2011

Space product assurance

Software metrication programme definition and implementation

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ECSS Secretariat
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Foreword

This Handbook is one document of the series of ECSS Documents intended to be used as supporting material for ECSS Standards in space projects and applications. ECSS is a cooperative effort of the European Space Agency, national space agencies and European industry associations for the purpose of developing and maintaining common standards.

The material in this Handbook is defined in terms of description and recommendation how to organize and perform the work of setting up and implementing a metrication programme that can be applied to space software projects. It does not provide, however, a detailed and exhaustive definition of all possible metrics that can be selected as part of the metrication programme.

This Handbook has been prepared by the ECSS-Q-HB-80-04 Working Group, reviewed by the ECSS Executive Secretariat and approved by the ECSS Technical Authority.

With permission from NEN (Dutch Standardization Institute – www.nen.nl) representing ISO in the Netherlands, this handbook contains extracts from ISO 15939:2007, adapted for the purpose of this document.

NOTE: The extracts are highlighted with grey shaded background and cross-reference to the ISO clause done in a footnote.

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Introduction

This Handbook describes the approach to be taken for the definition and implementation of an effective and efficient metrication programme for the development of software in a space project.

This Handbook provides guidelines and examples of software metrics that can be used in space system developments, in line with the requirements defined by [ECSS-E-40] and [ECSS-Q-80], given guidelines and examples to provide a coherent view of the software metrication programme definition and implementation.

This Handbook is intended to help customers in formulating their quality requirements and suppliers in preparing their response and implementing the work. This Handbook is not intended to replace textbook material on computer science or technology and software metrics, so repeating such material is avoided in this Handbook. The readers and users of this Handbook are assumed to posse’s general knowledge of computer science and software engineering.

In space projects, the demand of high quality software to be developed within allocated budget and time is a priority objective, particularly in presence of dependability requirements. Also the size of the operational software has increased significantly due to the increase in functionality to allow new challenging missions and to reply to increasingly sophisticated and demanding user requirements.

The space software development is therefore characterized by:

- High dependability of the software products, in both space and ground segments;
- Stringent schedule and cost estimates that are more and more accurate to enable reliable cost estimates for the overall project;
- Demand of high quality software, and
- Increasing productivity requirements.

To improve, suppliers should know what can be done better, and also what to look at in order to understand where lessons learnt can be applied to support the improvement.

Measurements are the only way to quantitatively assess the quality of a process or a product.

In presence of complex software projects reliable measures of both processes and products provide a powerful tool to software management for keeping the project in track and preserve the intended quality of the software product. Improvement of both the space software product and its development processes depends upon improved ability to identify, measure, and control essential parameters that affect software product and its development processes. This is the goal of any software metrication programme.

The main reasons for measuring software processes and products are:

— **To characterize** the existing processes and the status of products under development or operations, in order to gain a better understanding and support the overall verification of the software, as well as to acquire data/information for future assessments of similar processes/products.

- **To evaluate** the status of the project to determine its status and possible deviation from the established plans, and to support identification of actions to bring it back under control; the evaluation includes an assessment of an achievement of quality goals and an assessment of the impacts of technology and process improvements on products and processes.
- **To predict**, with the aim to improve the ability to plan. Measuring for prediction involves gaining understanding of relationships among processes and products and building models of these relationships, so that the observed values for some attributes can be used to predict others. The reason for that is to establish achievable goals for cost, schedule, and quality—so that appropriate resources can be applied. Predictive measures are also the basis for extrapolating trends, so estimates for cost, time, and quality can be updated based on current evidence. Projections and estimates based on historical data also help to analyse risks and make design/cost tradeoffs.
- **To improve**. Gathering quantitative information helps to identify roadblocks, root causes, inefficiencies, and other opportunities for improving product quality and process performance. Measures also help to plan and track improvement efforts.

Measures of current performance give baselines to compare against, so that it can be possible to judge whether or not the improvement actions are working as intended and what the side effects can be. Good measures also help to communicate goals and convey reasons for improving. This helps engage and focus the support of those who work within the processes to make them successful.

1 Scope

The scope of this Handbook is the software metrication as part of a space project, i.e. a space system, a subsystem including hardware and software, or ultimately a software product. It is intended to complement the [ECSS-Q-80] with specific guidelines related to use of different software metrics including their collection, analysis and reporting. Tailoring guidelines for the software metrication process are also provided to help to meet specific project requirements.

This Handbook provides recommendations, methods and procedures that can be used for the selection and application of appropriate metrics, but it does not include new requirements with respect to those provided by ECSS-ST-Q-80C Standard.

The scope of this Handbook covers the following topics:

- Specification of the goals and objectives for a metrication programme.
- Identification of criteria for selection of metrics in a specific project / environment (goal driven).
- Planning of metrication in the development life cycle.
- Interface of metrication with engineering processes.
- Data collection aspects (including use of tools).
- Approach to the analysis of the collected data.
- Feedback into the process and product based on the analysis results.
- Continuous improvement of measurement process.
- Use of metrics for process and product improvement.

This Handbook is applicable to all types of software of all major parts of a space system, including the space segment, the launch service segment and the ground segment software.

2 References

For each document or Standard listed, a *mnemonic* (used to refer to that source throughout this document) is proposed in the left side, and then the *complete reference* is provided in the right one.

ECSS Standards

[ECSS-S-ST-00-01]	ECSS-S-ST-00-01C, ECSS - Glossary of terms
[ECSS-Q-80]	ECSS-Q-ST-80C, Space Product Assurance – Software Product Assurance
[ECSS-E-40]	ECSS-E-ST-40C, Space Engineering – Software

ISO/IEC Standards

ISO 9126	ISO/IEC 9126 Software engineering - Product quality, Parts 1 to 4 (complete series)
ISO 9126-1	ISO/IEC 9126-1:2001 Part 1: Quality model
ISO 9126-2	ISO/IEC TR 9126-2:2003 Part 2: External metrics
ISO 9126-3	ISO/IEC TR 9126-3:2003 Part 3: Internal metrics
ISO 9126-4	ISO/IEC TR 9126-4:2004 Part 4: Quality in use metrics
ISO 12207	ISO/IEC 12207:2008 Information Technology - Software life cycle processes.
ISO 14143	ISO/IEC 14143 Information technology - Software measurement, Parts 1 to 6 (complete series)
ISO 14598	ISO/IEC 14598 Software engineering - Product evaluation, Parts 1 to 6 (complete series)
ISO 14598-1	ISO/IEC 14598-1:1999 Part 1: General overview
ISO 24765	ISO/IEC 24765, Systems and Software Engineering Vocabulary
ISO 15939	ISO/IEC 15939:2007 Software Engineering - Software Measurement Process
ISO 17799	ISO/IEC 17799:2005 Information technology - Code of practice for information security management
ISO 25000	ISO/IEC 25000:2005 Ed. 1 Software Engineering - Software product Quality Requirements and Evaluation (SQuaRE) - Guide to SQuaRE

Other ESA documents

SPEC	ESTEC Contract No. 12650/97/NL/NB(SC) - SPEC – Software Product Evaluation and Certification (complete series)
SPEC-I	ESTEC Contract No. 20421/06/NL/PA - SPEC Method Improvement
SPEC-I-QM	SPEC/QM SPEC Method improvement - Quality Model – Issue 1.F
SPEC-I-TN1	SPEC-I/TN1 SPEC Analysis results - Issue 1.F

SPEC-I -TN2	SPEC-I/TN2 Concept for Space Software Product Evaluation for Conformity WP4 - part 2- Issue 3.B
SPEC-I –TN3	SPEC-I/TN3 Concept for Space Software Product Evaluation for Conformity WP4 - part 3- Issue 3.2
SPEC-TN3	SPEC/TN3 Space Domain Specific Software Product Quality Models, Requirements and Related Evaluation Methods - Issue 3.4
SPEC-TN4.1	SPEC/TN4 part 1 Overview of existing software certification schemes - Issue 2
SPEC-TN4.2	SPEC/TN4 part 2 Concept for Space Software Product Evaluation and Certification - Issue 2
SPEC-TN4.3	SPEC/TN4 part 3 Concept for Space Software Product Evaluation and Certification - Issue 2

Reports and articles

CHALMERS	Chalmers University of Technology Presentation - Department of Computer Engineering - Dependability and Security Modelling and Metrics
EADS-ST	Astrium-ST- Astrium ST internal documents
FENTON	"Software Metrics - A Rigorous & Practical Approach" (second edition)
	Norman E. Fenton, Shari Lawrence Pfleeger
NASA-1740	NSS 1740.13 "NASA Software Safety Standard" February 1996
NASA-8719	NASA-STD-8719.13A Software Safety, 15 September 1997
NIAC	Common Vulnerability Scoring System - Final Report and Recommendations by the Council, 12 October 2004
NIST-1	NIST and Federal Computer Security Program Managers Forum IT
	Security Metrics Workshop - A Practical Approach to Measuring Information Security: Measuring Security at the System Level, 21 May 2002
NIST-2	NIST Special Publication 800-55
	Security Metrics Guide for Information Technology Systems, July 2003
NIST-3	NIST Special Publication 800-35
	Guide to Information Technology Security Services, October 2003
SANS-1	SANS Institute - A Guide to Security Metrics - SANS Security Essentials GSEC Practical Assignment, Version 1.2, 11 July 2001
SANS-2	SANS Institute - Systems Maintenance Programs - The Forgotten Foundation and Support of the CIA Triad, GSEC v1.3, 10 January 2002
SEC-FIN	VTT Technical Research Centre of Finland Publications 544
	Process Approach to Information Security Metrics in Finnish Industry and State Institutions, 2004
SUN-JAVA	SUN Java Coding Conventions

Websites

ISECOM	The Institute for Security and Open Methodologies (security)
	http://www.isecom.org/securitymetrics.shtml
EDUCAUSE	http://www.educause.edu
SEC-METRICS	Community website
	http://www.securitymetrics.org

SW-METRICS	International Software Metrics Organization
	http://www.swmetrics.org
SEC-DOCS	Security white papers and documents
	http://www.securitydocs.com
IEEE	http://www.ieee.com
IEEE-CS	http://www.computer.org
NIST	NIST Computer Security Resource Centre
	http://csrc.nist.gov/ispab/
COSMICON	The Common Software Measurement International Consortium
	http://www.cosmicon.com/
UKSMA	The UK Software Metrics Association
	http://www.uksma.co.uk/?action=0&what=90
ARMY-METRICS	Army Software Metrics Office
	http;//www.armysoftwaremetrics.org
PSSM	Practical Software & Systems Measurement
	http://www.psmsc.com

3 Terms, definitions and abbreviated terms

3.1 Terms from other documents

For the purpose of this document, the terms and definitions from ECSS-S-ST-00-01 and ECSS-Q-ST-80 apply.

3.2 Definitions in other clauses of the present HB

Subclause A.2 of Annex A includes the definitions for all characteristics/sub-characteristics contained in the quality model used in this Handbook

3.3 Terms specific to the present document

3.3.1 base measure

measure defined in terms of an attribute and the method for quantifying it.

[ISO 24765]

3.3.2 measure (noun)

variable to which a value is assigned as the result of measurement.

[ISO 24765]

3.3.3 measure (verb)

Make a measurement.

[ISO 24765]

3.3.4 measurement

act or process of assigning a number or category to an entity to describe an attribute of that entity.

NOTE "Category" is used to denote qualitative measures of attributes. For example, some important attributes of software products, e.g. the language of a source program (such as ADA, C, COBOL) are qualitative.

[ISO 24765]

3.3.5 metric

a quantitative measure of the degree to which a system, component, or process possesses a given attribute.

[ISO 24765]

3.3.6 quality model

defined set of characteristics, and of relationships between them, which provides a framework for specifying quality requirements and evaluating quality

[ISO 24765]

3.4 Abbreviated terms

For the purpose of this document, the abbreviated terms from [ECSS-S-ST-00-01] and the following apply:

Abbreviation	Meaning
CBO	coupling between objects
CM	configuration management
DDR	detailed design review
DIT	depth of inheritance tree
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
HOOD	Hierarchical Object Oriented Design
LOC	lines of code
LCOM	lack of cohesion method
MIPS	millions of instructions per second
MMI	man-machine interface
NASA	National Aeronautics and Space Administration
NOC	number of children
PPF	parametric polymorphic factor
RB	requirements baseline
RFD	request for deviation
RFW	request for waiver
SW PA	software product assurance
SPR	software problem report
SRR	system requirements review
UML	Unified Modelling Language
V&V	verification and validation
VG	cyclomatic complexity (McCabe)

4 Overview of the Handbook

4.1 Introduction

This subclause contains an introduction of the content of this Handbook, the intended audience and how to use it.

It introduces the rationale of the need of a metrication programme for space software projects based on [ECSS-E-40] and [ECSS-Q-80] requirements (especially this one).

The organization of this Handbook is reflected in detail in Figure 4-1. This Handbook is organized in seven main parts:

- Clause 1. Scope
- Clause 2: Normative references
- Clause 3: Terms, definitions and abbreviated terms.
- Clause 4: Overview of the Handbook
- Clause 5: A reference software quality model
- Clause 6: Measurement process
- Annex A: Definition of the quality model

The annex is provided for information only.

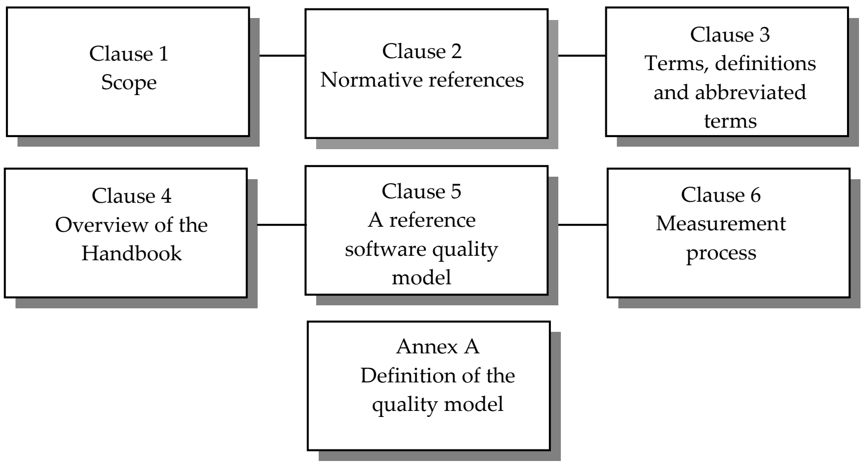


Figure 4-1:Organization of this document

4.2 Relation to other ECSS Standards

4.2.1 General

This subclause discusses how this Handbook interfaces with other ECSS series, namely the ECSS-Q series of standards (product assurance), ECSS-E series of standards (engineering) and the ECSS-M series of standards (management).

4.2.2 Software engineering

The interface of this Handbook to the ECSS-E branch is via [ECSS-E-40]; and in turn, the interface of [ECSS-E-40] to this Handbook is via the [ECSS-Q-80].

[ECSS-E-40] covers all aspects of space software engineering from requirements definition to retirement. It defines the scope of the space software engineering processes, including details of the verification and validation processes, and their interfaces with management and product assurance, which are addressed in the management (-M) and product assurance (-Q) branches of the ECSS system.

[ECSS-E-40] also defines the content of the document requirements definitions (DRDs) referenced inside the Standard.

[ECSS-E-40] is intended to help the customers to formulate their requirements and suppliers to prepare their responses and to implement the work. In this Standard requirements are defined in terms of what is to be accomplished, rather than in terms of how to organize and perform the necessary work. This allows the tailoring process to match the requirements to a particular profile and circumstances of a project. The goal of the tailoring is to select, modify or add adequately requirements in order to identify the quality ratio adequate to the actual project peculiarities.

There are no specific requirements in [ECSS-E-40] related to software measurement aspects, except those related to technical budgets management (e.g. 5.3.8 and 5.8.3.12), and a few requirements related to test coverage (several clauses of subclause 5.8.3.5). In addition, there are some requirements related to traceability (especially in subclause 5.8.3), which are connected to some extent to the metrication aspects of the software life cycle.

In addition, clause 5.4.2.1 of ECCS-E-40 demands that quality requirements are established and documented, as part of the technical specification. This is also reinforced in clauses 7.1 and 7.2 of [ECSS-Q-80].

All other aspects of software quality modelling and metrication are specified in the [ECSS-Q-80].

4.2.3 Software product assurance

This subclause contains an analysis of [ECSS-Q-80] requirements related to the definition and implementation of a metrication programme for space software projects.

[ECSS-Q-80] Standard presents software product assurance requirements to be met in a particular space project in order to provide confidence to the customer and to the suppliers that developed or reused software satisfies the requirements throughout the system lifetime. In particular, [ECSS-Q-80] presents requirements to ensure the software is developed to perform as expected and safely in the operational environment meeting the quality objectives agreed for the project.

[ECSS-Q-80] Standard is tailored in such a way that software product assurance requirements meet a particular space project and fulfil the specific objectives. In particular, clause 7 of [ECSS-Q-80] explains that software quality requirements (including safety and dependability) derives from requirements defined at system level.

Requirement 5.2.7.1 of [ECSS-Q-80] requires that quality models are used to specify software quality requirements (in quantitative terms as required in 7.1.2) and that they shall be derived from requirements at system level (as in § 7.1.1). Requirements 5.2.7.2, 6.2.5.3, 6.2.5.4 and 7.1.5 list quality characteristics, and process and product metrics that shall be part of the quality model.

Clause 7.1.4 requires that a metrication programme is defined and implemented in order to fulfil those quality requirements. Metrics are selected, collected and analysed against target values and reported corrective actions are taken when required (in [ECSS-Q-80] requirements 6.2.5.2, 7.1.4, 6.2.5.5 and 7.1.6).

All aspects related to process metrics are included in clause 6.2.5.

Clause 6.3.4 (coding) is special since it contains some requirements related to the coding standards and its relationship with the product quality requirements (not all related to process requirements).

4.2.4 Project management

The ECSS-M branch defines the requirements to be applied to the management of space projects. [ECSS-E-40] and [ECSS-Q-80] describe how the ECSS-M series of standards apply to the management of software projects. In addition, requirements that cannot be found in the M-branch because they are specific to software product assurance are defined in [ECSS-Q-80].

5 A reference software quality model

5.1 Introduction

The current situation in space system and software development is characterized by the increasing complexity of the end product and growing demands on the cost and time effectiveness as well as overall quality of the development process. In order to facilitate a continuous monitoring of the progress of the project it is essential to collect quantifiable evidence both for the product being developed and the process being performed.

[ECSS-Q-80] (ECSS Standard for software product assurance in space projects), in the same line as other industry standards, includes some requirements for the collection and analysis of a number of measures with this objective.

The main objective of the metrication framework as defined in this Handbook is to provide support in the selection of project specific quality model and metrics in order to facilitate a continuous feedback as a basis for the critical decisions to be taken throughout the project. In particular, metrication should enable the following goals:

- Communicate the project status throughout the project organization under the responsibility of quality assurance.
- Identify early and correct problems.
- Provide a basis for key tradeoffs (from both technical and management points of view) while taking into account the project constraints such as cost, schedule, quality, and functionality.
- Track specific project objectives.
- Defend and justify project decisions throughout the development life-cycle.
- Provide the supplier and the customer with an indication of the quality status of the software product

Metrication should be seen as a supporting activity to achieve these goals that complement the other quality assurance activities. As a stand-alone technique it does not provide suitable feedback, but it does it in the larger context of quality assurance.

Although the main purpose of the metrication as described in this document is the support of projects throughout the development processes, metrication is also part of process improvement activities. In addition to the activities of defining metric programs, capturing and evaluation of metric data which provide a basis for project monitoring, a systematic approach to metrication-based process improvement requires the selection of a common subset of metrics and their normalization at department or company level. The goal is the definition of a comparable set of data covering any type of software development projects. While this topic is addressed briefly in clause 6, full guidance for organizational metrication process improvements exceeds the scope of this Handbook.

In the following sections, several aspects of the metrication programme as well as the introduction of the reference quality model for the space software are presented.

As the presented quality model is to be used as a reference, and is required to be tailored for each project, several metric tailoring tables are included in this Clause, with the aim of facilitating selection of metric sets from two different perspectives: relevant software quality requirements and criticality category (applicability and target values).

5.2 Reference software quality model

As in the ISO standards, the first step in the evaluation of software is to select relevant quality characteristics, using a quality model that breaks software quality objectives down into different characteristics. Quality models for software evaluation often represent the totality of software quality attributes classified in a hierarchical tree structure of characteristics and sub-characteristics. A variety of quality models is available in the literature (see for example [ISO 9126], [SPEC], and [ISO 25000]). The quality model defined in this Handbook is derived from these references but focuses on a subset of the proposed models that cover the requirements in [ECSS-Q-80] and for which a quantitative evaluation is possible.

This quality model takes into account both process and product related characteristics relevant for space projects. Main characteristics taken into account are presented in below table 5-1.

The quality model proposed below is to be used as reference. It is expected to be tailored according to projects needs. It is recommended to select a subset of the metrics proposed below that support SW product quality characteristics representative for the project and beneficial for customer and supplier for analysis, design coding, testing, operation and maintenance.

For each of the characteristics defined, one or more quantifiable sub-characteristics are identified that together provide the quality characteristics that are considered for space projects. The selection of these characteristics is driven by the objective to provide a streamlined and cost-effective reference metrication approach for space software development.

The criteria used for the selection of characteristics/sub-characteristics of this quality model are the following:

- All characteristics / sub-characteristics that occur either in the [ECSS-E-40] or in the [ECSS-Q-80] are included.
- Many other characteristics / sub-characteristics proposed in [ISO 9126] are also considered, as authoritative references in the field of quality modelling.
- The quality model is then completed with a few additional characteristics / sub-characteristics proposed in other sources ([NASA-1740], [PSS-01-212], [EADS-ST], literature on metrics), but not in the main input references.

In order to reduce the size of the resulting quality model when following above approach, and to augment its usability, few reduction rules were applied:

- When a given sub-characteristic was found not measurable (i.e. no chance to find suitable metrics), then it was discarded.
- When a given sub-characteristic, even if measurable, was considered as providing very little or no added value to the project, then it was also discarded.
- In case that all sub-characteristics associated to a given characteristic were discarded, then the characteristic itself was also removed from the quality model.

In summary, the selection of the characteristics / sub-characteristics of this reference quality model is driven by pragmatic criteria (i.e. only a few characteristics, measurable, providing a significant added value, and specific to the objectives of a metrication program).

In Figure 5-1 the elements composing the software quality model are shown. This quality model takes into account both process and product related characteristics, therefore, in turn, it includes two categories of metrics: *product metrics*, related to measuring the products of the development, and *process metrics*, referring to measuring the processes themselves.

NOTE The ISO standards use detailed terminology for different types of measures: b*ase measure* or *direct measure* (measure functionally independent of other measures), *derived measure* or *indirect measure* (a function of two or more values of base measures), that are simplified within this Handbook corresponding to the so-called *(product or process) metrics*.

The ISO standards also identify the terms *external measures* (product properties during execution) and *internal measures* (internal attributes that capture static properties of the product) also specified in the ISO Standards are simplified within this Handbook corresponding to the so-called *product metrics*.

Each process or product metric is calculated by the use of a formula or analysis (measurement) deduced from combining different base measures from attributes of expected outputs or activities produced or performed at different stages in the project.

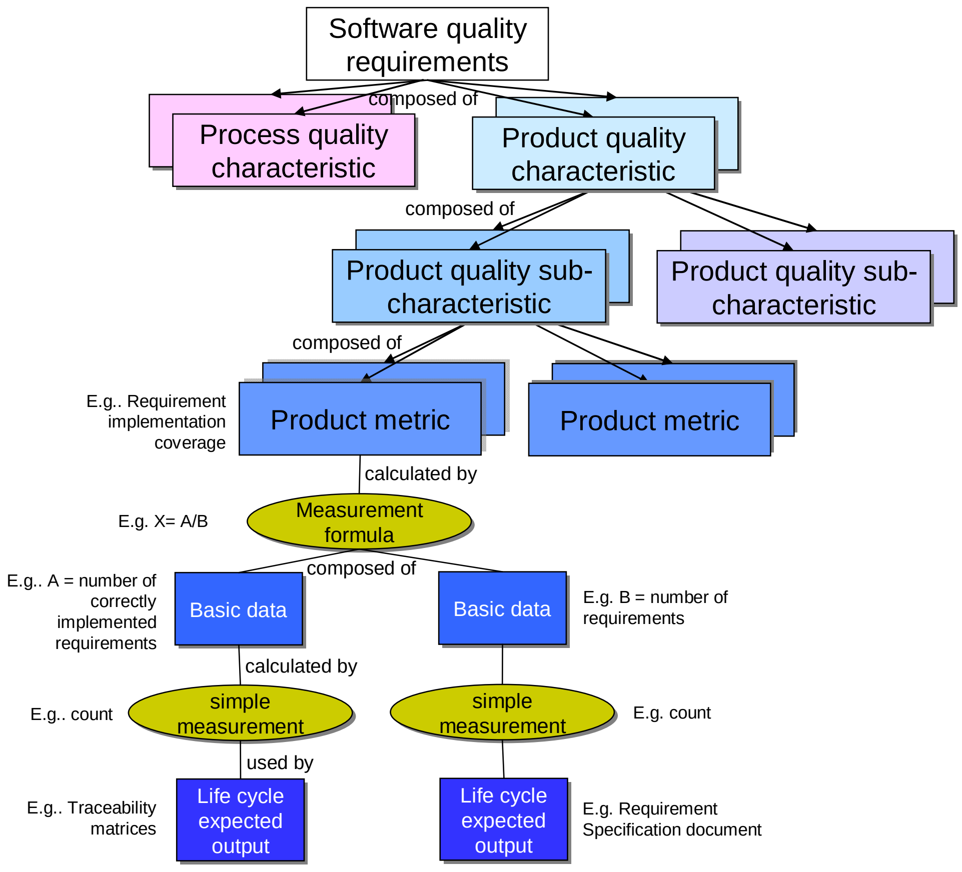

Software quality requirements
composed of
Process quality characteristic
Product quality characteristic
composed of
Product quality sub-characteristic
Product quality sub-characteristic
composed of
E.g.. Requirement implementation coverage
Product metric
Product metric
calculated by
E.g. X= A/B
Measurement formula
composed of
E.g.. A = number of correctly implemented requirements
Basic data
Basic data
E.g. B = number of requirements
calculated by
E.g.. count
simple measurement
simple measurement
E.g. count
used by
E.g.. Traceability matrices
Life cycle expected output
Life cycle expected output
E.g. Requirement Specification document

Figure 5-1: Elements of the software quality model

Table 5-1 presents the proposed reference quality model.

It is important to perform the software measurements in an efficient way and that the resulting measures are practical. Many software measurements can conveniently be made with the help of automatic tools and can be packaged as an evaluation module (see [ISO 14598-6]).

To achieve a continuous monitoring throughout the development life-cycle, it is necessary to identify the relevant phases for data capture and metric evaluation for the specific metrics. While some metrics are independent of the development progress, other metrics are only available after certain milestones have been reached.

In order to provide guidelines for this allocation of measurement activities to the project life cycle, this Handbook refers to the software processes as defined in [ECSS-E-40]. The following table presenting the proposed reference quality model indicates when each applicable metric should be collected and provided.

Annex A provides the full definition of the Quality Model and further guidance with regard to the allocation of individual quality characteristics and the related measurements to the individual processes.

Table 5-1: Proposed reference quality model

(Main) characteristic	Sub characteristic	Metrics	First provided at	Frequency
PRODUCT RELATED CHARACTERISTICS				
Functionality	Completeness	Requirement allocation	SRR	Every Review
		Requirement implementation coverage	PDR	Every Review
		Requirements completeness	PDR	Every Review
		V&V coverage	PDR	Every Review
	Correctness	SPR/NCR trend analysis	CDR	Every Review and Progress Meeting
		Requirement clarity	PDR	Every Review
		Suitability of development documentation	SRR	Every Review
		Adherence to coding standards	CDR	Every Review
	Efficiency	CPU margin	PDR	Every Review
		Memory margin	PDR	Every Review
Reliability	Reliability Evidence	Process reliability adequacy	SRR	Every Review
		SPR/NCR status (see NOTE 1)	CDR	Every Review and Progress Meeting
		Structural coverage	CDR	Every Review
	Correctness	(see above metrics for Functionality.Correctness subcharacteristic)		
	Testability	Requirement testability	PDR	Every Review
Maintainability	Complexity	Cyclomatic complexity (VG)	CDR	Every Review
		Nesting level	CDR	Every Review
		Lines of code (LOC)	CDR	Every Review
		Comment frequency	CDR	Every Review
	Testability	(see above metrics for Reliability.Testability subcharacteristic)		
	Modularity	Modular span of control	CDR	Every Review
		Modular coupling	CDR	Every Review
		Modular cohesion	CDR	Every Review
	Correctness	(see above metrics for Functionality.Correctness subcharacteristic)		
	Portability	Environmental software independence	DDR	Every Review
		System hardware independence	DDR	Every Review
	User doc. quality	User documentation clarity	CDR	Every Review
		User documentation completeness	CDR	Every Review
		User manual adequacy	CDR	Every Review

(Main) characteristic	Sub characteristic	Metrics	First provided at	Frequency
Reusability	Portability	See above Maintainability.Portability subcharacteristic		
	Reusability documentation	Reusability checklist	SRR	Every Review
	Reuse Modification	Reuse Modification rate	SRR	Every Review
Suitability for Safety	Safety Evidence	Safety activities adequacy	SRR	Every Review
	Correctness	(see above metrics for Functionality.Correctness subcharacteristic)		
Security	Security Evidence	Security checklist	SRR	Every Review
Usability	User doc. quality	See above Maintainability.User doc .quality subcharacteristic		
	User interface quality	Adherence to MMI standards	CDR	Every Review
PROCESS RELATED CHARACTERISTICS				
Software Development Effectiveness	Project development process level	Process assessment [ECSS-HB-Q-80-02]	(1)	(2)
	Project management effectiveness	Milestone tracking	1st Progress Meeting	Every Progress Meeting
		Effort tracking	1st Progress Meeting	Every Progress Meeting
		Code size stability	DDR	Every Review and Progress Meeting
		Requirement stability	SRR	Every Review
		RID/action status	SRR	Every Review and Progress Meeting
		V&V progress (see NOTE 2)	PDR	Every Review and Progress Meeting

(1) Before the relevant processes start.

(2) Process Assessment is done just once unless an improvement program is initiated and the correspondent reassessment is planned.

NOTE 1 NOTE: SPR/NCR status is also regarded as both product metric (from the reliability point of view: number of bugs fixed on the product so far) and process metric (from the progress point of view: known problems to be corrected as an estimation of pending work).

NOTE 2 Some metrics like V&V progress may be considered as both product metric (from the correctness point of view: number of V&V activities performed so far) and process metric (from the progress point of view: remaining time for the completion of all planned V&V activities).

The definition of each characteristic, subcharacteristic is presented in Annex A. In addition, Annex A provides the details for each metric, when and how to calculate it.

5.3 Tailoring the metrication programme

The metrication programme defined covers all aspects of the quality model and identifies metrics as well as the relevant basic data to be collected and the evaluation of these data. For individual projects several decisions should be made, starting with the identification of relevant quality objectives, the selection of individual metrics, the decision on evaluation criteria (thresholds of permissible values, configuration of metrics with regard to project-specific circumstances).

This Handbook does provide guidelines for the top-level tailoring, i.e. the identification of a suitable subset of measurements on the basis of software aspects such as criticality. It does not provide detailed guidance on a concrete definition of the basic data. Such definitions are strongly dependent on the specific aspects of each project, such as the development environment and, in particular, on the specific programming language chosen for the project. Extensive guidance for these aspects can be found in the literature (e.g. [Fenton], [PSSM]). Similarly, literature provides information with regard to commonly used permissible ranges (target values) for a variety of basic data (e.g. [ISO 9126], [SUN], [PSSM]). Some examples are also given below. These can provide a starting point for a metrication programme.

The reported experience shows that a tuning of a metrication programme also depends very much on the application area, as well as on the development environment and even on cultural aspects. In general the detailed definition should be based on company experience and be refined in a continuous adaptation process. This aspect exceeds the scope of this guideline and is thus omitted.

Different metric tailoring tables are included in this subclause, with the aim of facilitating the selection of the metric sets from one main perspective: criticality category (applicability and target values).

Finally, next subclause develops some more detailed guidelines as an example to show how to tailor the whole metrication programme for a specific project, following the different metrication programme definition steps.

Tables 5-2 and 5-3 provide the tailoring of metrics depending on the criticality category (following the classification scheme proposed in [ECSS-Q-80]), which is done from two different perspectives:

1. (Table 5-2) Applicability of each metric depending on the criticality category:
    (a) MANDATORY: when this metric is derived from a requirement in [ECSS-Q-80] or [ECSS-E-40].
    (b) RECOMMENDED: the metric is not required by [ECSS-Q-80] or [ECSS-E-40], but it can bring significant added value to the project.
    (c) OPTIONAL: the metric is for internal use only (i.e. delivery to the customer is not required).
2. (Table 5-3) Proposed *target value* for each metric depending on the software criticality category:

    In general, these values should be taken as *indicators* that have been collected from the practical experience in past space projects. They are not necessarily the best target values for all future projects and situations; they should be tuned up on a case-by-case basis.

    There are even some metrics for which no generic target values are proposed, because they are strictly project-dependant.

Table 5-2: Applicability of the metrics depending on the criticality category

Metric name	Criticality category			
	A	B	C	D
Requirement allocation	M	M	M	M
Requirement implementation coverage	M	M	M	M
Requirement completeness	R	R	R	O
V&V coverage (RB/TS levels)	M	M	M	M
V&V coverage (unit/integration levels)	M	M	M	O
SPR/NCR trend analysis	M	M	M	M
Requirement clarity	R	R	R	O
Documentation suitability	M	M	M	M
CPU margin	M	M	M	R
Memory margin	M	M	M	R
Cyclomatic complexity (VG)	M	M	M	M
Nesting level	M	M	M	M
Lines of code (LOC)	M	M	M	M
Comment frequency	M	M	M	M
Adherence to coding standards	M	M	M	M
Requirement testability	M	M	M	R
Modular span of control	M	R	R	O
Modular coupling	M	R	R	O
Modular cohesion	M	R	R	O
Process reliability adequacy	M	M	M	O
SPR/NCR status	M	M	M	M
Structural coverage	M	M	M	M
Environmental software independence	M	M	M	R
System hardware independence	M	M	M	R
Reusability checklist	M	M	M	M
Reuse modification rate	M	M	M	M
Safety activities adequacy	M	M	R	O
Security checklist	M	M	M	M
User documentation clarity	R	R	R	R
User documentation completeness	R	R	R	R
User manual suitability	M	M	M	M
Adherence to MMI standards	M	M	M	M
Process assessment [ECSS-HB-Q-80-02]	M	M	R	R
Milestone tracking	M	M	M	M
Effort tracking	M	M	M	M

Metric name	Criticality category			
	A	B	C	D
Code size stability	M	M	M	M
Requirement stability	M	M	M	R
RID/action status	M	M	M	M
V&V progress	M	M	M	M

Table 5-3: Target value for metric depending on criticality category

Metric name	Proposed target value/ criticality category			
	A	B	C	D
Requirement allocation	1	1	1	1
Requirement implementation coverage	1	1	1	1
Requirement completeness	0	0	0	0
V&V coverage	1	1	1	1
SPR/NCR trend analysis	P.D.	P.D.	P.D.	P.D.
Requirement clarity	0	0	0	0
Documentation suitability	1	1	1	1
CPU margin	P.D.	P.D.	P.D.	P.D.
Memory margin	P.D.	P.D.	P.D.	P.D.
Cyclomatic complexity (VG)	10	10	15	20
Nesting level	5	5	5	7
Lines of code (LOC)	50	50	50	75
Comment frequency	0.3	0.3	0.3	0.2
Adherence to coding standards	1	1	1	1
Requirement testability	0.8	0.8	0.8	0.8
Modular span of control	2	5	7	9
Modular coupling	3	3	4	4
Modular cohesion	2	2	3	3
Process reliability adequacy	1	1	1	1
Statement Coverage (Source Code)	1	1	1	
Statement Coverage (Object Code)	1	P.D.	P.D.	P.D.
Decision Coverage (Source Code)	1	1	1	P.D.
Modified Condition & Decision Coverage (Source Code)	1	P.D.	P.D.	P.D.
SPR/NCR status	(1)	(1)	(1)	(1)
Environmental software independence	0.95	0.95	0.95	0.9

	Proposed target value/ criticality category			
System hardware independence	0.95	0.9	0.85	0.85
Reusability checklist	1	1	1	1
Reuse modification rate	P.D.	P.D.	P.D.	P.D.
Safety activities adequacy	1	1	1	1
Security checklist	1	1	1	1
User documentation clarity	0	0	0	0
User documentation completeness	0	0	0	0
User manual suitability	1	1	1	1
Adherence to MMI standards	1	1	1	1
Process assessment [ECSS-HB-Q-80-02]	(2)	(2)	(2)	(2)
Milestone tracking	P.D.	P.D.	P.D.	P.D.
Effort tracking	P.D.	P.D.	P.D.	P.D.
Code size stability	P.D.	P.D.	P.D.	P.D.
Requirement stability	P.D.	P.D.	P.D.	P.D.
RID/action status	(3)	(3)	(3)	(3)
V&V progress	1	1	1	1

(1) *SPR/NCR status*: Although no specific target values are identified for this metric, some sample acceptance criteria can be proposed:

- No major/critical SPR/NCR should remain open at SW-AR.

- All minor SPRs/NCRs still open at SW-AR should be properly covered by temporary or permanent RFW.

(2) *Process assessment [ECSS-HB-Q-80-02]:* Target values according to the table on subclause A.3.3.32 (Target Capability Levels).

(3) *RID/action status*: Similarly to the SPR/NCR status metric, no specific target values can be proposed. Some acceptance criteria that can be used for this metric are:

- No major RID from previous milestones should remain open at next milestone.

- All RIDs/actions still open at SW-AR should be declared as 'open work' and a proper action plan to close them should be agreed with the customer.

5.4 Detailed tailoring guidelines

The tailoring of a metrication programme for an individual project requires several steps:

1. Identification of relevant project characteristics (main characteristics and sub-characteristics, see Annex A).

   The project objectives and the product properties determine which of the quality characteristics in the generic quality model are relevant.

   Examples:

- A software product developed to be a text editor is in general not safety critical and thus the 'Suitability for Safety' characteristic should not be considered.
- A software project with no reuse of existing software and with no requirements to produce any software to be reused should not include the 'Reusability' characteristic in its metrication program.
- A software project with no security requirements should not include the 'Security' characteristic as part of its metrication program.

From this point of view, none of the characteristics proposed in the quality model of Annex A can be considered as mandatory. They only become mandatory if the related product property is relevant to the current project.

2. Selection of related base/derived metrics.

   In general several metrics are available for each sub-characteristic in the quality model. It is necessary to determine which ones should be captured within a project. Only some of them may be captured in the same project.

   Example:

   - Lines of code is a metric related to maintainability in the quality model proposed.

3. Allocation of measurement activities to life cycle processes.

   After having selected the quality characteristics and the required base and derived metrics it is necessary to identify to which life cycle processes is allocated the capture and evaluation of each metric.

   Examples:

   - Code size stability or comment frequency are clearly linked to code. They can not be captured during the architectural design phase, for example.
   - Failure rate measurement is often restricted to high-level test phases (e.g. integration, system testing, acceptance), but excluded at unit testing level.

4. Definition of evaluation / analysis criteria.

   In order to use the metrication results as a means of monitoring and steering the project it is necessary to define limits or thresholds that individual metrics should not exceed.

   Examples:

   - Some literature recommends that cyclomatic complexity of a single subprogram (function, procedure) does not exceed the limit 10, in case of mission-critical software.
   - A reuse criteria used in many space projects is that, for a given reused product, no more than 20 % of the code should be changed. Otherwise the product should be treated as newly-developed software.
   - Other space projects define that there should not be any open critical problem in the problem report list submitted for acceptance, and no more than 5 open urgent problems.

5. Detailed definition of data to be captured.

   Once the base metrics required for the selected measures have been identified (steps 1 and 2 above), it is also necessary to detail several aspects of the data collection process:

   - The exact definition of the attributes to be measured.

- The sources of these attributes.
- The capture frequency.
- The capturing mechanism.

Examples:

- The base measure LOC (lines of code) can be defined to include comment and blank lines or to exclude them. The source of these data can be the whole source code or excluding libraries. The capture can be defined to take place for each build or only for the final code before each milestone. The capturing can be done in an automatic way (either within the software development environment or using specific tools), or manually by reading the data from an editor (not recommended for large products, of course!).
- Similarly, the failure rate measure can exclude certain types of faults (e.g. routine ones), and can be captured only before each milestone or on a continuous basis.
- Test coverage can be defined as system test coverage (i.e. versus requirements), unit test coverage (i.e. versus statements/conditions), or both.

It is out of scope of this Handbook to detail above steps 4 and 5 on a global basis. However, further guidance to support these activities is provided in subclause A.3 of Annex A (detailed definition of metrics).

6 Measurement process

6.1 Introduction

The complete measurement process consists in the following activities, as depicted in Figure 6-1:

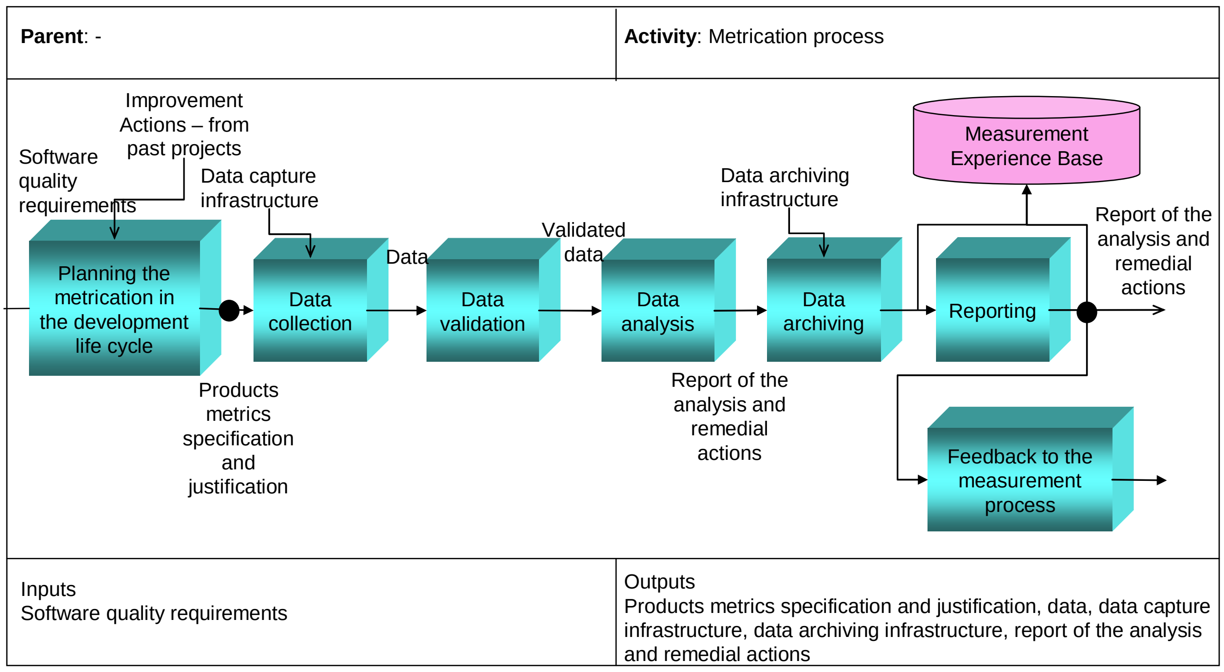

Parent: -
Activity: Metrication process
Improvement Actions – from past projects
Software quality requirements
Data capture infrastructure
Data archiving infrastructure
Measurement Experience Base
Report of the analysis and remedial actions
Validated data
Data
Planning the metrication in the development life cycle
Data collection
Data validation
Data analysis
Data archiving
Reporting
Products metrics specification and justification
Report of the analysis and remedial actions
Feedback to the measurement process
Inputs
Software quality requirements
Outputs
Products metrics specification and justification, data, data capture infrastructure, data archiving infrastructure, report of the analysis and remedial actions

Figure 6-1: Metrication process activities

As defined in [ISO 12207], the purpose of this process is to collect and analyse data relating to the products developed and processes implemented, to support effective management of the processes and to objectively demonstrate the quality of the products.

As a result of successful implementation of metrication process, the following is achieved:

a. Commitment is established and sustained to implement the measurement process within the space project;

b. The measurement information requirements are identified;

c. An appropriate set of measures, driven by the information requirements are identified and developed

d. Measurement activities are identified and performed;

e. The required data are collected, stored, validated, analysed, and the results interpreted;

f. Information products are used to support decisions and provide an objective basis for communication; and

g. The measurement process and measures are evaluated and

h. Feedback produced for the improvement of this same measurement process.

The following subclauses detail each of these activities. These clauses are heavily based on the [ISO 15939].

6.2 Planning of metrication in the development life cycle

Planning aspects of metrication should include:

1. Characterize the project quality requirements and select the metrics to be collected.
2. Define data collection, and analysis procedures.
3. Define criteria for validating the metrics and the measurement process.
4. Define resources and infrastructure for measurement tasks.
5. Define how reporting will be performed
6. Review and approve the measurement plan.
7. Provide resources and infrastructure for measurement tasks

6.2.1 Characterize the project quality requirements and select the metrics to be collected

The supplier should ensure that general quality requirements applicable to the software system are identified, and that they are documented in the technical specification (TS). They are derived from the reliability, safety, maintainability and quality requirements of the system.

In addition, relevant project characteristics should be identified as they will also support the selection and interpretation of the metrics to be collected. They provide the context of measurement and any constraints and assumptions to be considered within the measurement process.

Each quality requirement is to be mapped into one or several quality characteristics which, in turn, lead to the identification of the associated sub-characteristics and the selection of a proper metric set (see above clause 5). This quality model is to be defined ad-hoc for each project. The reference quality model provided in Clause 5 and in Annex A can be used to support this definition. For each metric, target values are to be defined intended to be used as quantitative representations of the quality requirements (evaluation criteria).

Annex A defines a format to define each metric.

6.2.2 Define data collection and analysis procedures

Procedures for data collection, including storage, validation and analysis should also be defined in the here called ‘measurement plan’ that is to be included in the software product assurance plan as the ‘product metrics specification and justification’.

The procedures should specify how data will be collected, (indicating in which life-cycle processes and activities) and how and where they will be stored. [1)]

The supplier specifies data collection actions (procedures) needed to obtain actual values for each metric. This also includes specification of time schedules and responsibilities for the data collection and analysis. The data collection and storage is often performed with the use of tools and special infrastructure, and this should also be planned for and scheduled accordingly.

The measurement precision and metrics accuracy should be defined as part of the measurement plan, e.g. any statistical models to be applied, including input data requirements or sampling strategies.

When in the development life cycle and in which of its processes (including the management, supporting, and also this measurement process), the metrics are to be calculated should be identified. The set of measurements can imply a change in the development process (e.g. added activities for these metrics to be taken, added tools to be used for their collection, storage and analysis).

The procedures should also specify the data analysis method(s), and format and methods for reporting the information products. The range of tools that would be required to perform the data analysis should be identified. [2)]

If measurement results are out of boundaries or inconclusive, the supplier should also define contingency actions like extra evaluations.

All items used during this metrication activity such as the collected data, analysed data, information products, tools parameters and selected information needs should be placed under configuration management. [3)]

This can be the same configuration management procedure used in other parts of the project [ISO 15939].

6.2.3 Define criteria for validating the metrics and the measurement process

Criteria for determining whether both the data collected and analysed and the measurement process itself were having the required quality to satisfy the project requirements. The criteria should be defined at the beginning, and act as success criteria.

Example criteria for the evaluation of the data collected are the accuracy of a measurement procedure and the reliability of a measurement method. However, it might be necessary to define new criteria and measures for evaluating the metrics. Examples of criteria for the quality of the measurement process are timeliness and efficiency. [4)]

Each project should define its own criteria to validate both data collected and analysed and the measurement process.

In addition, the validation activities should be performed at different stages (as soon as the data is collected, after the analysis of the data, at the end of the measurement process). For each criteria, the time in which it is to be used and reported should be defined per process.

[1)] [Adapted from ISO/IEC 15939 clause 4.2.4.1]
[2)] [Adapted from ISO/IEC 15939 clause 4.2.4.2]
[3)] [Adapted from ISO/IEC 15939 clause 4.2.4.3]
[4)] [Adapted from ISO/IEC 15939 clause 4.2.5.1]

6.2.4 Define resources and infrastructure for measurement tasks

It should be ensured that, at a minimum, skilled individuals are assigned the responsibility for the following typical roles:

- *Measurement sponsor*, that should be responsible for the measurement planning and ensuring that resources are provided (also referred here as *measurement owner*);
- *Measurement provider*, who calculates and collects the data (also referred here as *producer*)
- *Measurement user*, who uses the analysed data (also referred here as *target audience*);
- *Measurement analyst*, who analyses the data using the analysis methods;
- *Measurement librarian*, who keeps the integrity of the captured and stored data.

The number of roles shown above does not imply the specific number of people required to perform the roles. The number of people is dependent on the size and structure of the space project. These roles can be performed by as few as one person for a small project. [5)]

In particular, only three of these five roles are used in the quality model that is presented in Annex A: *owner*, *provider* and *target audience*. The owner role is intended to cover also the analyst and librarian roles in the sense that he/she is responsible for ensuring them.

The required infrastructure for the performance of the different measurement process' steps and detailed metrics collection is also defined in the measurement plan. The data collection, storage and analysis are often performed with the use of tools and special infrastructure, and this should also be planned for and scheduled accordingly. If special training of personnel is required, this should also be included in the plan. This training may be needed by quality assurance or quality control organization or the entire development team being responsible of the performance of the different measurement process activities.

Both configuration management and security procedures (and tools if necessary) to preserve the integrity of the data captured, analysed and stored should be planned for.

6.2.5 Define how reporting will be performed

As part of the measurement planning, procedures about the reporting mechanisms and reporting lines should also be defined. These reporting mechanisms include the procedures for deviation notifications and investigation, and the possible corrective actions to be performed accordingly. The reporting periodicity and the life cycle milestones and events when these reports should be available should also be documented in the measurement plan.

6.2.6 Review and approve the measurement plan

The results of measurement planning should be reviewed and approved by project responsibles.

Measurement planning should be fed back from previous measurement cycles and should take into consideration improvements and updates proposed, if any. [6)]

These possible improvements should be analysed regarding any impact (resources, schedule, tools, etc) in current measurement plan.

[5)] [Adapted from ISO/IEC 15939 clause 4.1.2.1]
[6)] [Adapted from ISO/IEC 15939 clause 4.2.6.1]

6.2.7 Provide resources and infrastructure for measurement tasks

After the measurement plan is approved, the roles identified in the measurement plan are assigned to individuals within the project, including the responsible of the planning process itself. The resources and tools defined in the plan should also be provided (often to be acquired and always to be deployed for that specific project) to those implementing all the activities defined in the measurement plan.

Any training needs should also be provided in support to the performance of the metrication activities and the use of the methods and tools identified for this project.

Tools for collecting data (so called in figure above 'data capture infrastructure') as for example static code analysers and test coverage monitors, are typical tools required.

This can involve the modification or extension of existing tools, and the calibration and testing of the tools. [7)]

For the storage of the data, 'data archiving infrastructure' should also be provided (acquired if necessary). This infrastructure can be different than the one used to capture the data, since it might be composed by e.g. databases or storage media including project context information.

Both configuration management and security procedures to preserve the integrity of the data captured, analysed and stored should be implemented as planned.

6.3 Data collection

The data collection should include the following aspects:

1. Integrate procedures
2. Collect data

6.3.1 Integrate procedures

These tasks are intended to be performed in accordance with the planning information produced during the tasks described in subclause 6.2.

The first action to be performed is the integration of the data generation, collection and storage tasks into the relevant processes.

This may imply changing current engineering and development processes to accommodate data generation, collection and storage activities, tools and any other resources needed. Integration involves a trade-off between the extent of impact on existing processes and the requirements of the measurement process. The required changes should be minimized.

The extent of integration varies depending on the type of measures and the information needs. The data collected can include extra measures defined specifically to evaluate the information products or performance measures to evaluate the measurement process. [8)]

The integrated data collection procedures should be communicated to the measurement providers.

The objective of this communication is to ensure confidence that measurement providers understand exactly the type of data that are expected, the format that is required, the tools to use, when to provide data, and how frequently. For example, the measurement providers can be trained on how to

[7)] [Adapted from ISO/IEC 15939 clause 4.2.7.1]
[8)] [Adapted from ISO/IEC 15939 clause 4.3.1.1]

complete a defect data form, to ensure that they understand the defect classification scheme, and the meanings of different types of effort (such as isolation and correction effort). [9]

The data analysis and reporting should also be integrated into the relevant project processes and performed on a regular basis. [10]

6.3.2 Collect data

After integration, when collecting the data, the selected metrics are measured using the designated formula (so called *measurement formula* in Figure 5-1).

This can be accomplished by manual or automated means. Data can be collected, for example, with a static code analyser that calculates values for product metrics every time a module is checked into a configuration management system. Data also can be collected, for example, by completing a defect data form and sending it to the measurement librarian. [11]

6.4 Data validation

In addition, the collected data should be validated. The measurement owner should take necessary actions to ensure the quality of the collected data. The actions should include validating automated tools for data collection and checking data by human procedures.

Data validation can be performed by inspecting against a checklist or by checking the data or metric value obtained against the defined valid range of values. The checklist can be constructed to validate that missing data are minimal, and that the values make sense. Examples of the latter include checking that a defect classification is valid, or that the size of a component is not ten times greater than all previously entered components. In case of anomalies, the measurement provider(s) is consulted and corrections to the raw data made where necessary. [12]

The defined procedures for these anomaly corrections should be used [ISO 15939].

6.5 Data analysis

The collected data is analysed.

Data can be aggregated, transformed, or re-coded prior to analysis, following the measurement function defined for each metric. During this analysis task, data are processed to produce the planned indicators. The amount of rigor in the analysis should be determined by the nature of the data and the information needs. [13]

Afterwards, the data analysis, results are interpreted.

The measurement analyst(s) should be able to draw some initial conclusions based on the results. [14]

Actual values for the different metrics collected are analysed. In case of undesirable values, the cause is analysed, thereby allowing the target audience to understand and react to problems.

[9] [Adapted from ISO/IEC 15939 clause 4.3.1.2]
[10] [Adapted from ISO/IEC 15939 clause 4.3.1.3]
[11] [Adapted from ISO/IEC 15939 clause 4.3.2.1]
[12] [Adapted from ISO/IEC 15939 clause 4.3.2.3]
[13] [Adapted from ISO/IEC 15939 clause 4.3.3.1]
[14] [Adapted from ISO/IEC 15939 clause 4.3.3.2]

Actual values are compared with target values when they are assigned. Actual values should be analysed in order to identify *outlier* values (i.e. values deviating from predefined thresholds). Outlier values often indicate problems or unusual conditions. Explanation of outlier values should always be justified: sometimes there are good reasons for outlier values and in that case, there might be no reason for corrective actions. Contingency actions should be taken when required following the defined procedures in the measurement plan.

All interpretations should take into account as defined for each of the metrics within its context.

The data analysis results, indicators, interpretations, justifications and supporting information should be all documented and reported including the relevant analysis performed, the corrective actions undertaken and the status of these actions. [15)]

The reports of the analysis obtained should be reviewed (with the measurement providers and the target audience) to ensure that the analysis was performed and interpreted properly, that the information needs were satisfied and that potential corrective actions are feasible. It can be an informal "self-review", or a more formal inspection process depending on each project's requirements.

6.6 Data archiving

The collected data should always be stored, including any context information necessary to verify, understand, or evaluate the data. The data store may not be an automated tool. It is possible to have a paper-based data store, for example, in the situation where only a few measures are collected for a short period of time in a small organization. [16)]

This storage should be performed both for the project under development, and also for historical reasons, i.e. to enable the eventual use of this collected and analysed data by other. This measurement database is intended to capture analysis results from past iterations of the cycle of the metrics that have been found to be useful by the organization, previous evaluations of information products, and evaluations of previous iterations of the measurement process. This database should be a persistent storage since its data (for example, analysis results, historical data, and lessons learned) are intended to be reused in future iterations of the measurement process.

6.7 Reporting

All results from the different metrication activities should be documented in the software product assurance report of the project (subclauses 6.2.5 and 7.1 of [ECSS-Q-80]).

These analysis results are documented and communicated to the target audience, to the measurement providers, and other project responsibles, so the level of reporting can vary depending on recipients (e.g. internal to the project, external customer). The reporting intervals to which target audience and with respect to life cycle events (e.g. milestones, reviews) should follow what is defined in the measurement plan.

NOTE Activities described in sections 6.2 to 6.5 are often performed in an iterative manner, therefore reporting activities are iterative too.

Example guidelines for reporting the analysis results are provided in [ISO 15939]

[15)] [Adapted from ISO/IEC 15939 clause 4.3.3.2]

[16)] [Adapted from ISO/IEC 15939 clause 4.3.2.2]

6.8 Feedback to the measurement process

This subclause describes how to enhance the metrication programme based on lessons learnt from its practical application. This activity often involves both customer and supplier and consists of the following tasks:

1. Evaluate analysis results and the measurement process
2. Identify potential improvements

6.8.1 Evaluate analysis results and the measurement process

Both the metrics analysis results and the measurement process itself are evaluated for measurement process improvement.

The metrication process analysis results are evaluated against the specified evaluation criteria and conclusions on strengths and weaknesses of the analysis results drawn. This evaluation may be accomplished through an internal or independent audit. The inputs to this evaluation are the performance measures, the analysis results, and the target audience feedback.

The evaluation of the analysis results can conclude that some measures may be removed, for example, if they no longer meet a current information need. [17)]

The effectiveness of each measurement formula used by the measurement process requires being evaluated using pre-defined criteria. The following are examples of such criteria (i.e. this is not an exhaustive list):

- Usefulness of analysis results: The extent to which the analysis results produced by the measurement process are actually used for decision making in the management or technical processes supported by measurement.
- Confidence in the analysis results: The extent to which the consumers of the analysis results (target audience) have confidence in the raw data, derived metrics and interpretations incorporated in the analysis result.
- Evidence of fitness for purpose of the analysis results: The extent to which the analysis results can be demonstrated to be effective for the identified information need.
- Understandability of the results: The ease with which the metrics and the interpretations of them can be understood by the intended target audience.
- Satisfaction of the assumptions of a quality model: The extent to which assumptions inherent in the model on which a metric is based have been satisfied (e.g. data distributions, measurement scales, units of measure, sample size).
- Accuracy of a formula: The extent to which the procedure implementing a formula conforms to the intended evaluation method. An accurate procedure produces results similar to the true (or intended) value of the base measure.
- Repeatability of an evaluation method: The degree to which the repeated use of the formula in the same organization following the same evaluation method under the same conditions (e.g. tools, individuals performing the measurement) produces results that can be accepted as being identical. Subjective evaluation methods tend to experience lower repeatability than objective methods. Random measurement error reduces repeatability. [18)]

[17)] [Adapted from ISO/IEC 15939 clause 4.4.1.1]
[18)] [Adapted from ISO/IEC 15939 Annex D]

The measurement process is evaluated against the specified evaluation criteria and conclusions on strengths and weaknesses of the measurement process drawn. The evaluation of measurement process may be accomplished through an internal or independent audit or process assessment. [19)]

The expected benefits for supplier and customer of this evaluation and improvement process can be, by instance:

- For the Supplier: Software process and product improvements (company wide benefits, software engineering process group)
- For the Customer: Potential improvements in current developments, better process follow up at suppliers.

The quality of the measurement process influences the quality of the information products. The inputs to this evaluation are the performance measures, the information products, and the target audience feedback. [20)]

The goodness of a process may be judged by assessing its capability or by measuring and evaluating its performance. This Handbook, as a whole, can be used as a reference model for assessing the capability of a measurement process.

The following criteria can be regarded as potential information needs of the measurement process responsible. The measurement process described in this Handbook can be applied to produce results that address the information needs identified by the measurement process responsible.

- Timeliness: The measurement process should provide the analysis results in time to support the requirements of the target audience. Appropriate timing depends on the schedule of the management or technical process being supported.
- Efficiency: The measurement process should not cost more to perform than the value of the information that it provides. The more efficient the process, the lower its cost, and the greater the cost/benefit.
- Defect containment: The measurement process should avoid the introduction of erroneous data and results, while removing any that do get introduced as thoroughly and soon as possible.
- Customer satisfaction: The users of information products should be satisfied with the quality of the analysis results and the performance of the measurement process in terms of timeliness, efficiency, and defect containment. Satisfaction can be affected by the user's expectation of the level of quality and performance to be provided.
- Process conformity: The execution of measurement activities should conform to any plans and procedures developed to describe the intended measurement process. This may be judged by quality management audits or process capability assessments. [21)]

Lessons learned from the evaluation can take the form of strengths and weaknesses of the information products, of the measurement process, of the evaluation criteria themselves, or experiences in measurement planning (for example, "there was great resistance by the measurement providers in collecting a specific measure at a specific frequency"). [22)]

[19)] [Adapted from ISO/IEC 15939 clause 4.4.1.2]
[20)] [Adapted from ISO/IEC 15939 clause 4.4.1.2]
[21)] [Adapted from ISO/IEC 15939 Annex E]
[22)] [Adapted from ISO/IEC 15939 clause 4.4.1.3]

6.8.2 Identify potential improvements

Potential improvements from above evaluations are identified to both the metrics and the analysis results and the measurement process.

The measurement responsible should review the results of the evaluation and the validity of the evaluation process, indicators and metrics applied. Feedback from the review should be used in order to improve the evaluation process and evaluation modules. When it is necessary to improve the evaluation modules the data collection for extra indicators should be included, in order to validate them for later use.

Such “Improvement Actions” should be used in future instances of the initial metrication planning activity. Cost/benefit analyses when selecting the “Improvement Actions” to implement should be considered. Some improvements might not be cost effective, so not to be performed for that project.

Measurement process changes should be provided to the overall measurement process responsible, and measurement product changes should be provided to the measurement analyst(s). If no potential improvements are identified, then that should also be communicated to the measurement process responsible.

In [ISO 15939] and other literature sample activities to improve the efficiency of the metrication programme can be found.

Annex A Definition of the quality model

A.1 General introduction

This annex presents the details of the reference quality model proposed, as a synthesis result of several quality models proposed in the main input sources and bibliography used for the preparation of this Handbook.

This framework is proposed as an example of quality model that can be used for the selection of the relevant characteristics and sub-characteristics specific to each project, as well as some metrics that can be used to measure them.

Projects developed by using OO approach will find some OO metrics in Annex A.4 to use where traditional metrics cannot be applied straightforward, e.g. to measure the complexity of the design, They are proposed as an alternative to the classic metrics (i.e. modular span of control), which are not considered appropriate for an object-oriented design approach.

The annex includes a glossary of the definitions used for each characteristic / sub-characteristic of the quality model, including detailed traces to the origin of each definition.

After this, it is also detailing each proposed metric defined in previous table 5-1 as contributing to the different sub-characteristics.

A.2 Characteristics and sub-characteristics definition

As a complement to the previous Table 5-1, this subclause provides the definitions for the different characteristics / sub-characteristics included in the quality model, as well as an indication where the definition is taken from.

A.2.1 Functionality

The capability of the software product to provide functions which meet stated and implied needs when the software is used under specified conditions.

Definition taken from: [ISO 9126], [SPEC]

Mentioned in: [ECSS-E-40], [ECSS-Q-80]

A.2.1.1 completeness

The capability of the software to provide full implementation of the functions required.

Definition taken from: [SPEC]

Mentioned in: [ECSS-E-40], [NASA-1740]

A.2.1.2 correctness

The degree to which a system or component is free of faults in its specification, design and implementation.

Definition taken from: [SPEC] [ISO 24765]

Mentioned in: [NASA-1740]

A.2.1.3 efficiency

The capability of the software product to provide appropriate performance, relative to the amount of resources used, under stated conditions.

Definition taken from: [ISO 9126], [SPEC]

NOTE In [ECSS-S-ST-00-01] it is defined differently but re-defined in this Handbook as more related to software quality aspects.

A.2.2 Reliability

The capability of the software product to maintain a specified level of performance when used under specified conditions.

Definition taken from: [ISO 9126], [SPEC]

NOTE In [ECSS-S-ST-00-01] it is defined very similarly but here it specifically refers to software.

Mentioned in: [ECSS-Q-80]

A.2.2.1 reliability evidence

The capability to show that software reliability analysis and assessment have been performed during the software development process.

Definition taken from: [SPEC]

A.2.3 Maintainability

Ability of an item under given conditions of use, to be retained in, or restored to, a state in which it can perform a required function, when maintenance is performed under given conditions and using stated procedures and resources.

Definition taken from: [ECSS-S-ST-00-01]

NOTE In [ISO 9126], [SPEC] it is referring to The capability of the software product to be modified. Modifications can include corrections, improvements or adaptation of the software to changes in environment, and in requirements and functional specifications.

Mentioned in: [ECSS-Q-80]

A.2.3.1 modularity

The degree to which a system or computer program is composed of discrete components such that a change to one component has minimal impact on other components

Definition taken from: [ISO 24765]

Mentioned in: [ECSS-Q-80]

A.2.3.2 testability

Extent to which an objective and feasible test can be designed to determine whether a requirement is met.

Definition taken from: [ISO 24765]

Mentioned in: [ECSS-E-40]

A.2.3.3 complexity

the degree to which a system's design or code is difficult to understand because of numerous components or relationships among components

Definition taken from: [ISO 24765]

A.2.4 Reusability

Degree to which a software module or other work product can be used in more than one computer program or software system.

Definition taken from: [ECSS-Q-80]

A.2.4.1 reusability documentation

The availability of specific documentation which provides information about reusing the software; e.g. in which context and applications the component can be reused, with which constraints, which additional tests might be needed for the new operational environment.

Definition taken from: [New definition proposed in this Handbook]

A.2.4.2 portability

Capability of software to be transferred from one environment to another.

Definition taken from: [ECSS-E-40], [ECSS-Q-80]

A.2.4.3 reuse modification

Percentage of estimated modifications applied to every existing software component.

Definition taken from: [New definition proposed in this Handbook]

A.2.5 Suitability for safety

System state where an acceptable level of risk with respect to fatality, injury or occupational illness, damage to launcher hardware or launch site facilities, damage to an element of an interfacing manned flight system, the main functions of a flight system itself, pollution of the environment, atmosphere or outer space, and damage to public or private property.

Definition taken from: [ECSS-S-ST-00-01]

NOTE Similar definitions can be found in *[ISO 9126]*(The capability of the software product to achieve acceptable levels of risk of harm to people, business, software, property or the environment in a specified context of use) and in *[SPEC]* (The capability of software to allow and contribute to the safe behaviour of the system).

Mentioned in: [ECSS-E-40], [ECSS-Q-80]

A.2.5.1 safety evidence

The capability to show that software safety analysis and assessment have been performed during the software development process.

Definition taken from: [SPEC]

A.2.6 Security

Protection from unauthorized access or uncontrolled losses or effect.

Definition taken from: [ECSS-S-ST-00-01]

NOTE Similar definition can be found in *[ISO 9126](The capability of the software product to protect information and data so that unauthorized persons or systems cannot read or modify them and authorized persons or systems are not denied access to them). A different composed definition is found in [ISO 17799] (Preservation of confidentiality, integrity and availability of information:*

- Confidentiality: Ensuring that information is accessible only to those authorized to have access.
- Integrity: Safeguarding the accuracy and completeness of information and processing methods.
- Availability: Ensuring that authorized users have access to information and associated assets when required)

Also mentioned in: [ECSS-E-40], [ECSS-Q-80]

A.2.6.1 security evidence

The capability to show that software security analysis and assessment have been performed during the software development process.

Definition taken from: [SPEC]

A.2.7 Usability

Capability of the software to be understood, learned, used and liked by the user, when used under specified conditions.

Definition taken from: [ECSS-Q-80]

A.2.7.1 user documentation quality

Those attributes of the software that determine the adequacy of the documentation related to software development, maintenance and operation.

Definition taken from: [SPEC]

A.2.7.2 user interface quality

The capability of the software product that allow the user to efficiently and reliably communicate with the software.

Definition taken from: [New definition proposed in this Handbook]

A.2.8 Software development effectiveness

Extent to which planned activities are realized and planned results achieved.

Definition taken from: [ECSS-S-ST-00-01]

NOTE Other definitions are found in *[ISO 9126]* (The capability of the software product to enable users to achieve specified goals with accuracy and completeness in a specified context of use) and in *[SPEC]* (The degree of success/quality of the development process to which the software was subjected, which provide valuable indications of the product quality).

Mentioned in: [ECSS-Q-80]

A.2.8.1 project development process level

The results of a software process assessment showing the achieved level of capability of the processes composing the software development process on the basis of the analysis of the current practices within the organization producing the software.

Definition taken from: [SPEC]

A.2.8.2 project management effectiveness

The capability of the software development process to asses the quality in the management of the process in a specified context of use.

Definition taken from: [New definition proposed in this Handbook]

A.3 List of proposed metrics

A.3.1 Introduction

This subclause provides a detailed description of all metrics proposed to measure the above presented characteristics and sub-characteristics.

The list of proposed metrics is not exhaustive. This Handbook is not intended to provide an extensive tutorial on metrics, something that is well covered by the existing literature on software metrics. What is proposed here is a realistic set of metrics that cover the needs of most space projects. The selection of metrics is based on the applicable [ECSS-Q-80] requirements complemented by the practical experience of the working group members accumulated in real projects.

A.3.2 Standard metric template

The following metric template is used for all metrics described in this annex. For each field in the template, a brief description is provided together with one example.

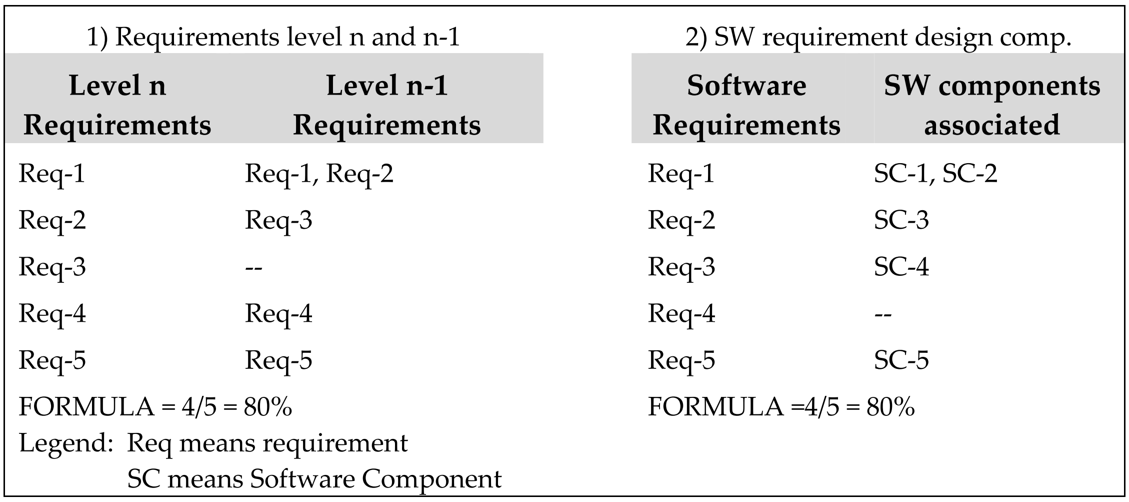
Main Characteristic	Related main characteristic(s) of the quality model proposed in this document. *e.g. Functionality*
Sub Characteristic	Related sub characteristic(s) of the quality model proposed in this document. *e.g. Completeness*
Metric title	Descriptive name for this metric. *e.g. Functional requirements implementation coverage*
Goal	Purpose of this metric (i.e. what is it collected for). *e.g. Check whether all functional requirements are validated by system tests with positive results*
Owner / Producer	Identification of owner and producer of this metric. *e.g. owner: SW PA responsible; producer: development team*
Target audience	Identification of the target audience for this metric (i.e. users). *e.g. developers, project manager*
Evaluation method	Measurement method used for the computation of this metric. *e.g. Functional testing results analysis; Specification analysis* Indicate also whether this metric can be collected by manual means, automatic means, or both. *Manual means such as: checklists, peer review, visual inspection.* *Automatic means: results produced by SW tools*
Formula	Computation formula for this metric. *e.g.* $X = A/B$ A = *number of correctly implemented functional requirements confirmed by executed tests (System tests)* B = *number of functional requirements* *Any specific precision and accuracy requirements should be also defined in here*
Interpretation of measured value	Target value(s) for this metric. *e.g.* $0 <= X <= 1$*, the closer to 1 the better* An indication of different target values depending on the criticality can be also given here.

Life cycle phase	Indication of when this metric should be collected and provided (according to [ECSS-E-40] terminology): *Collected at (possible values):Software related system engineering / SW requirements & architecture engineering / SW design & implementation engineering / SW validation / SW delivery & acceptance / SW verification process / SW operation / SW maintenance* *Provided at: SRR, PDR, DDR, CDR, QR and SW-AR* Also possible: an indication of start phase + frequency: *Example 1: As of PDR, to be provided at every review.* *Example 2: To be provided for each progress meeting.*
Applicability	Applicability of this metric depending on the criticality using the criticality categories provided in [ECSS-Q-80] subclause D.1. *Possible values:* *MANDATORY (quality requirement)* *RECOMMENDED (some added value to the project expected)* *OPTIONAL (for internal use only)* *N/A (not applicable)* **Note: The applicability of the different questions of the checklists proposed for few metrics in this quality model are illustrative and therefore they shall be tailored and re-defined according to the requirements for each project.**
Pre-conditions	Any prerequisite that is to be satisfied before this metric can be collected and analysed. *e.g. Functional Requirements data will be available and accessible*
Report format	How the results of this metric will be presented. *e.g. bar chart, document, pie chart.*
Other remarks	

A.3.3 Detailed description of all metrics

A.3.3.1 Requirement allocation

Main Characteristic	Functionality
Sub Characteristic	Completeness
Metric name	Requirement allocation
Goal	This metric identifies the relationship among: - Higher level requirements and software level requirements; - SW requirements and SW design.
Owner / Producer	Owner: development leader Producer: development team
Target audience	Development leader, SW PA manager, V&V leader
Evaluation method	Traceability matrices contained in SW requirements and SW design documentation.
Formula	X= A/B, where: A = number of system level requirements for software that have one or more trace to SW requirements or SW design components; B = number of system level requirements for software
Interpretation of measured value	0 <= X <= 1, the closer to 1 the better
Life cycle phase	Collected during software related system engineering, SW requirements & architecture engineering, SW design & implementation engineering processes. Provided at SRR, and updated afterwards (e.g. PDR) as required.
Applicability	- MANDATORY for all criticality categories.
Pre-conditions	Availability of traceability matrices.
Report format	*See example below.*
Other remarks	



1) Requirements level n and n-1

Level n Requirements	Level n-1 Requirements
Req-1	Req-1, Req-2
Req-2	Req-3
Req-3	--
Req-4	Req-4
Req-5	Req-5

FORMULA = 4/5 = 80%

2) SW requirement design comp.

Software Requirements	SW components associated
Req-1	SC-1, SC-2
Req-2	SC-3
Req-3	SC-4
Req-4	--
Req-5	SC-5

FORMULA =4/5 = 80%

Legend: Req means requirement
SC means Software Component

Figure A-1: Example of report format for requirements allocation

A.3.3.2 Requirement implementation coverage

Main Characteristic	Functionality
Sub Characteristic	Completeness
Metric name	Requirement implementation coverage
Goal	This metric provides the percentage of requirements that are implemented and properly verified in the product.
Owner / Producer	Owner: V&V leader Producer: V&V team
Target audience	SW PA manager, V&V leader, development leader
Evaluation method	Analysis of traceability matrices (i.e. requirements versus verification method), eventually with the aid of some automatic tools (e.g. DOORS).

Formula	X= A/B, where:
	A = number of correctly implemented requirements confirmed by verification (including test, inspection, review, and analysis, validation);
	B = number of requirements

Interpretation of measured value	0 <= X <= 1, the closer to 1 the better Those requirements that are not implemented or verified should be covered by the corresponding RFD/RFW.
Life cycle phase	Collected during SW validation and verification processes. Provided at PDR, and updated afterwards as required.
Applicability	- MANDATORY for all criticality categories.
Pre-conditions	Availability of traceability matrices.
Report format	Textual (just a figure).
Other remarks	

A.3.3.3 Requirement completeness

Main Characteristic	Functionality
Sub Characteristic	Completeness
Metric name	Requirement completeness
Goal	This metric provides the number of remaining open points in the requirements.
Owner / Producer	Owner: SW PA manager Producer: development team
Target audience	SW PA manager, development leader
Evaluation method	Analysis of requirements documents (e.g. SRD, ICDs), eventually with the aid of automatic tools (e.g. macros).
Formula	X= A/B, where: A= number of requirements containing TBCs/TBDs; B= total number of requirements;
Interpretation of measured value	0 <= X <= 1, the closer to 0 the better
Life cycle phase	<u>Collected</u> during SW requirements & architecture engineering. <u>Provided</u> at PDR, and updated afterwards as required.
Applicability	- RECOMMENDED for criticality categories A, B and C. - OPTIONAL for criticality category D.
Pre-conditions	- Availability of requirements documents. - Use of a supporting tool is highly recommended.
Report format	TBC/TBD table as an annex to the relevant document (including summary figures).
Other remarks	The metric does not take into consideration the *relevance* of each TBC/TBD (otherwise it would become too complicate to be collected). It just provides an *indication* of the number of open points.

A.3.3.4 V&V coverage

Main Characteristic	Functionality
Sub Characteristic	Completeness
Metric name	V&V coverage
Goal	This metric allows identifying whether the test and validation strategy (including inspection, review, and analysis) is complete. It is applicable to each element subject to V&V activities (e.g. requirement, SW design component, internal and external interface).
Owner / Producer	Owner: V&V leader Producer: V&V team
Target audience	SW PA manager, V&V leader, development leader
Evaluation method	Analysis of traceability matrices included in the DJF.
Formula	X = A/B, where: A = number of elements covered by at least one V&V activity (test, inspection, review or analysis); B = total number of element;
Interpretation of measured value	0 <= X <= 1, the closer to 1 the better No specific target value for each criticality level.
Life cycle phase	Collected during SW validation and verification processes. Provided at PDR, and updated afterwards as required..
Applicability	At requirements level (RB/TS): - MANDATORY for all criticality levels. At unit/integration level: - MANDATORY for criticality levels A to C. - OPTIONAL for criticality levels D and E.
Pre-conditions	- Completion of V&V planning activities for each phase. - Availability of relevant traceability matrices.
Report format	See example below.
Other remarks	This metric can be treated as a single metric for all verification levels (unit, integration, TS and RB), or can be decomposed into individual metrics for each level.

Table A-1: Example of V&V coverage reporting

Requirements Specification	Validation Test Procedure	Status
Req-1	Proc-1	Defined
Req-2		Not yet defined
Req-3	Proc-2	Defined
	Proc-3	Defined

FORMULA = 2/3 = 66%

A.3.3.5 SPR/NCR trend analysis

Main Characteristic	Functionality, Maintainability, Reliability, Suitability for safety
Sub Characteristic	Correctness
Metric name	SPR/NCR trend analysis
Goal	This metric provides a graphical representation of the evolution of SPR/NCR correction over time, classified by SPR/NCR severity levels.
Owner / Producer	Owner: SW PA manager Producer: CM responsible
Target audience	SW PA manager, development leader, V&V leader, CM responsible
Evaluation method	Analysis of SPR/NCR database.
Formula	There is no formula associated to this metric.
Interpretation of measured value	- The graphic exhibit convergence between number of raised and fixed problems. The lower the gap between these numbers the better. - At a certain point during testing, the number of new discovered problems should remain stable. This can be used as test completion criteria.
Life cycle phase	Collected during SW verification and validation, SW delivery and acceptance, SW operation and SW maintenance processes. Provided at CDR and updated afterwards for each milestone or progress meeting.
Applicability	- MANDATORY for all criticality categories.
Pre-conditions	- SPR/NCR procedure defined and implemented. - A good policy to classify SPRs/NCRs by severity level (e.g. critical, major, minor) should be also in place. - SPR/NCR system that allows identifying those NCRs that are software-related. - Availability of supporting tools to analyse the SPR/NCR database is strongly recommended.
Report format	Graphical (cumulative chart) – *See example below*
Other remarks	Only software-related NCRs will be considered.

Table A-2: Example of summary of NCR-SPR recorded

SPR Identification	Raised Date	Fixed Date	Severity Level
SPR1	2/05/04	10/06/03	C
SPRn	3/10/05	17/12/05	NC

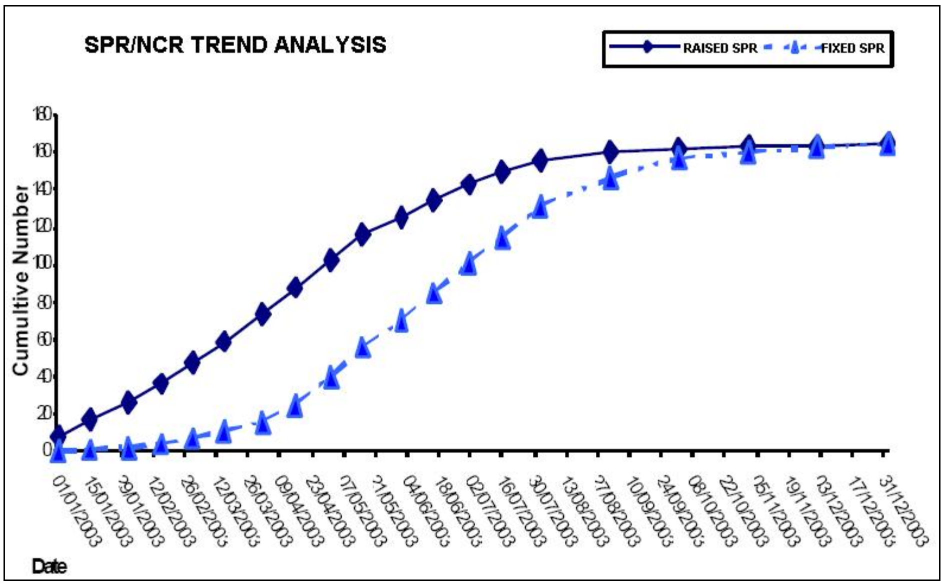


Figure A-2: Example of SPR/NCR trend analysis

A.3.3.6 Requirement clarity

Main Characteristic	Functionality, Maintainability, Reliability, Suitability for safety
Sub Characteristic	Correctness
Metric name	Requirement clarity
Goal	This metric provides an indication of the quality of the requirements.
Owner / Producer	Owner: SW PA manager Producer: development team
Target audience	SW PA manager, development leader
Evaluation method	Analysis of requirements documents (SRD, ICDs), eventually with the aid of some automatic tools.
Formula	X= A/B, where: A= number of ambiguous statements within the requirements documents; B= total number of statements within the requirements documents
Interpretation of measured value	0 <= X <= 1, the closer to 0 the better
Life cycle phase	Collected during SW requirements & architecture engineering. Provided at PDR, and updated afterwards as required.
Applicability	- RECOMMENDED for criticality categories A, B and C. - OPTIONAL for criticality category D.
Pre-conditions	- Availability of requirements documents. - Use of supporting tools is strongly recommended.
Report format	Tool dependant.

Other remarks	Ambiguous requirements are those that can have multiple meanings or those that seem to leave to the supplier the decision whether or not to implement a requirement. According to [SPEC]: *Ambiguous phrases* = *Weak phrases* + *Optional phrases*. *Weak phrases* contain at least one of the words: adequate, as appropriate, as applicable, but not limited to, normal, if practical, timely, as a minimum. *Optional phrases* contain at least one of the words: can, may, optionally.

A.3.3.7 Suitability of development documentation

Main Characteristic	Functionality, Maintainability, Reliability, Suitability for safety
Sub Characteristic	Correctness
Metric name	Suitability development documentation
Goal	This metric provides a subjective assessment of the adequacy of the development and V&V documentation.
Owner / Producer	Owner: SW PA manager Producer: development team, V&V team
Target audience	SW PA manager, development leader, V&V leader
Evaluation method	Documentation suitability checklist *(see sample checklist below)*
Formula	X = A/B, where: A = sum of Yes or N/A answers to the questions in the checklist B = total number of questions
Interpretation of measured value	The measured value will be 100% (i.e. all questions either positively answered or found not applicable).
Life cycle phase	<u>Collected</u> during SW validation and verification processes. <u>Provided</u> at SRR, and updated afterwards as required.
Applicability	- MANDATORY for criticality categories A to D.
Pre-conditions	- Availability of the relevant documentation. - Availability of team members to answer the checklist.
Report format	Answered checklist.
Other remarks	- The proposed checklist covers both development and V&V documentation. - The proposed target values might seem quite strict, but this is not the case: For the lower criticality categories the answer to most questions is probably N/A.

Table A-3: Sample checklist for Suitability of development documentation

No	Question	Supporting Evidence	Mark (Y,N,NA)
1	The software interfaces are completely and correctly specified		
2	The software requirement completely implements the system architecture and system requirements in terms of functional and performance specifications, software product quality requirements, security specifications, human factors engineering specifications, data definition and database requirements.		
3	The software requirements completely and consistently cover the HW/SW and SW/SW interfaces protocol definitions.		
4	The software requirements completely and consistently describe interactions and assumptions.		
5	A recognized method for software design is adopted and applied consistently.		
6	The architectural design defines the major components of the software and the interfaces between them.		
7	The architectural design defines or references all external interfaces.		
8	The architectural design document is complete, covering all the software requirements.		
9	The control flow between the components is defined.		
10	For each component the following information is detailed: data input, functions to be performed and data output.		
11	Re-used components are clearly identified and properly documented.		
12	Data structures interfacing components are defined include: description of each element (e.g. name, type, dimension); relationships between the elements (i.e. the structure); range of possible values of each element; initial values of each element.		
13	The detailed design defines all components.		
14	All software verification and validation activities are documented.		
15	All the test procedures and data are in accordance with the test plans, namely in which respect to: the type of test to be performed, (e.g. functional, robustness, performance, usability, etc), test coverage goals		
16	The unit, integration, system and acceptance tests are properly documented reporting test design, cases, procedures and reports.		

No	Question	Supporting Evidence	Mark (Y,N,NA)
17	The following activities are covered in project plans: - development; - software product assurance; - specification, design and customer documents to be produced; - configuration and documentation management; - verification, testing and validation activities; - maintenance.		
18	SW development standards are defined and applied.		
19	Procedures and project standards include provision for all criticality categories of software included in the project.		
20	Detailed validation test and validation documentation (data, procedures and expected results) are consistent with the defined validation strategy.		
21	Validation test procedures, data and expected results are specified.		
22	All software verification and validation activities are planned and reported.		
23	Verification activities ensure that the product meets the quality, reliability, maintainability and safety requirements (stated in the requirements).		

A.3.3.8 Adherence to coding standards

Main Characteristic	Functionality, Maintainability, Reliability, Suitability for safety
Sub Characteristic	Correctness
Metric name	Adherence to coding standards
Goal	This metric provides a subjective assessment of the adherence to the applicable coding standards.
Owner / Producer	Owner: SW PA manager Producer: development team
Target audience	SW PA manager, development leader
Evaluation method	Coding standards checklist, to be filled in with the help of static analysis tools. - Rules covered by automatic tools are expected to be verified for 100% of the code. - Sample code size will be specified for those rules to be verified manually (at least 5% of the code should be inspected). - No sample checklist is provided because this is strictly project/company dependant.
Formula	X = A/B, where: A = sum of Yes or N/A answers to the questions in the checklist B = total number of questions
Interpretation of measured value	The measured value should be 100% (i.e. all questions either positively answered or found not applicable). No specific target value identified for each criticality category.
Life cycle phase	Collected during SW validation and verification processes. Provided at CDR, and updated afterwards as required.
Applicability	- MANDATORY for criticality categories A to D.
Pre-conditions	- Availability of the relevant documentation. - Availability of team members to answer the checklist. - Use of static analysis tools to support data collection is strongly recommended.
Report format	- Static analysis reports (textual and graphic, tool dependant). - Answered checklist for each manually inspected module.
Other remarks	Even if no specific target values are identified (i.e. all applicable questions should be answered for the inspected modules), tailoring of this metric is possible from the point of view of sample code size, e.g.: - 10% of code should be inspected for levels A to C (in particular, 100% of the assembler code). - 5% of code should be inspected for level D

A.3.3.9 CPU margin

Main Characteristic	Functionality
Sub Characteristic	Efficiency
Metric name	CPU margin
Goal	This metric allows verifying whether the SW product fulfils its CPU margin requirements at a given phase of the development.
Owner / Producer	Owner: SW development leader Producer: development team
Target audience	Development leader, V&V leader, SW PA manager
Evaluation method	Analysis of technical budgets versus applicable requirements.

Formula	X = A/B, where:
	A= CPU power used (i.e. MIPS);
	B= Total CPU power (i.e. MIPS)

Interpretation of measured value	The estimated or measured CPU margin should be greater or equal than the required margin for the phase. Target values for this metric are strictly project dependant. Example: 50% CPU use at PDR; 75% CPU use at SW-AR.
Life cycle phase	Collection should start during the SW requirements & architecture engineering (preliminary estimation), and then continue during next phases. Provided at PDR and updated afterwards for each review.
Applicability	- MANDATORY for criticality categories A to C. - RECOMMENDED for criticality category D.
Pre-conditions	Availability of technical budgets updated for each review.
Report format	- Dedicated SW budget report as part of the DJF. - Global CPU margin should be indicated in the conclusions of that document.
Other remarks	This metric is at the beginning based on estimations (for the initial phases), which then are replaced by actual measures (during SW validation and acceptance).

A.3.3.10 Memory margin

Main Characteristic	Functionality
Sub Characteristic	Efficiency
Metric name	Memory margin
Goal	This metric allows verifying whether the SW product fulfils its memory margin requirements at a given phase of the development.
Owner / Producer	Owner: SW development leader Producer: development team
Target audience	Development leader, V&V leader, SW PA manager
Evaluation method	Analysis of technical budgets versus applicable requirements.

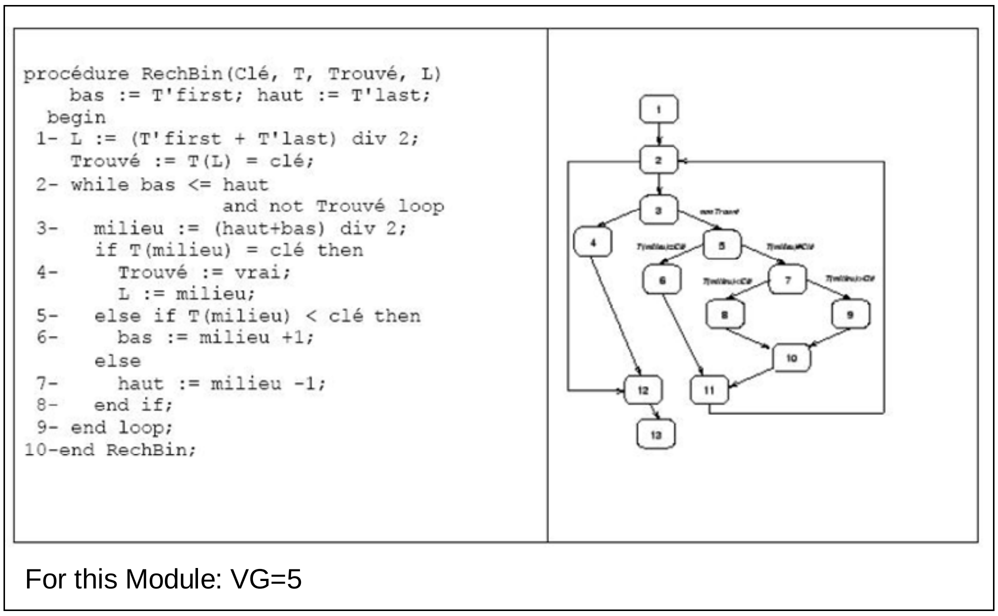
Formula	X = A/B, where:
	A = memory size used;
	B = total memory size

Interpretation of measured value	The estimated or measured memory margin should be greater or equal than the required margin for the phase. Target values for this metric are strictly project dependant. Example: 60% memory use at PDR; 75% memory use at SW-AR.
Life cycle phase	Collection should start during the SW requirements & architecture engineering (preliminary estimation), and then continue during next phases. Provided at PDR and updated afterwards for each review.
Applicability	- MANDATORY for criticality category A to C. - RECOMMENDED for criticality category D.
Pre-conditions	Availability of technical budgets updated for each review.
Report format	- Dedicated SW budget report as part of the DJF. - Global memory margin should be indicated in the conclusions of that document.
Other remarks	This metric is at the beginning based on estimations (for the initial phases), which are replaced later by actual measures (during SW validation and acceptance).

A.3.3.11 Cyclomatic complexity (VG)

Main Characteristic	Maintainability
Sub Characteristic	Complexity
Metric name	Cyclomatic complexity
Goal	This metric provides an indication of the code complexity, based on the number of linearly independent test paths for each subroutine.
Owner / Producer	Owner: development leader Producer: development team
Target audience	SW PA manager, development leader, V&V leader
Evaluation method	Static code analysis with the support of automatic tools.
Formula	The cyclomatic complexity of a single routine (function or procedure) is defined as: VG = (number of edges) - (number of nodes) + 2 Then, the cyclomatic complexity of a module is defined as: X = average VG for all routines in the module
Interpretation of measured value	In general, the lower the cyclomatic complexity the more simple and more testable a software product is. However, low complexity at routine level can increase granularity at design level. Therefore, a good compromise is to be reached for both properties. Proposed thresholds for the different criticality categories: VG target value for A-B software: 10 VG target value for C software: 15 VG target value for D software: 20 Further tailoring can be done in terms of allowed exceptions to these thresholds (such as multiple-choice statements or error-handling code).
Life cycle phase	Collected during SW validation and verification processes. Provided at CDR, and updated afterwards as required.
Applicability	- MANDATORY for criticality categories A to D.
Pre-conditions	- Coding activity finished (at least for a significant part of the product). - Availability of a static analysis tool (except maybe for small portions of assembler code).
Report format	- Tool dependant, but tabular and graphical results should both be provided (including summary figures). *See sample in Figure A-3 below.* - Cyclomatic complexity results can be presented at routine level or at module level.

Other remarks	- Remedial actions for modules/routines exceeding the threshold can be: redesign, code inspection, additional unit testing. - Adding comments to the code is not a good solution: poor design should be redesigned, not commented. - An alternative metric to the cyclomatic complexity is the *essential complexity*, where a more fair treatment is given to multiple-choice statements (they only count as one for the complexity).



```
procédure RechBin(Clé, T, Trouvé, L)
    bas := T'first; haut := T'last;
  begin
 1- L := (T'first + T'last) div 2;
    Trouvé := T(L) = clé;
 2- while bas <= haut
                 and not Trouvé loop
 3-   milieu := (haut+bas) div 2;
      if T(milieu) = clé then
 4-     Trouvé := vrai;
        L := milieu;
 5-   else if T(milieu) < clé then
 6-     bas := milieu +1;
      else
 7-     haut := milieu -1;
 8-   end if;
 9- end loop;
10-end RechBin;
```

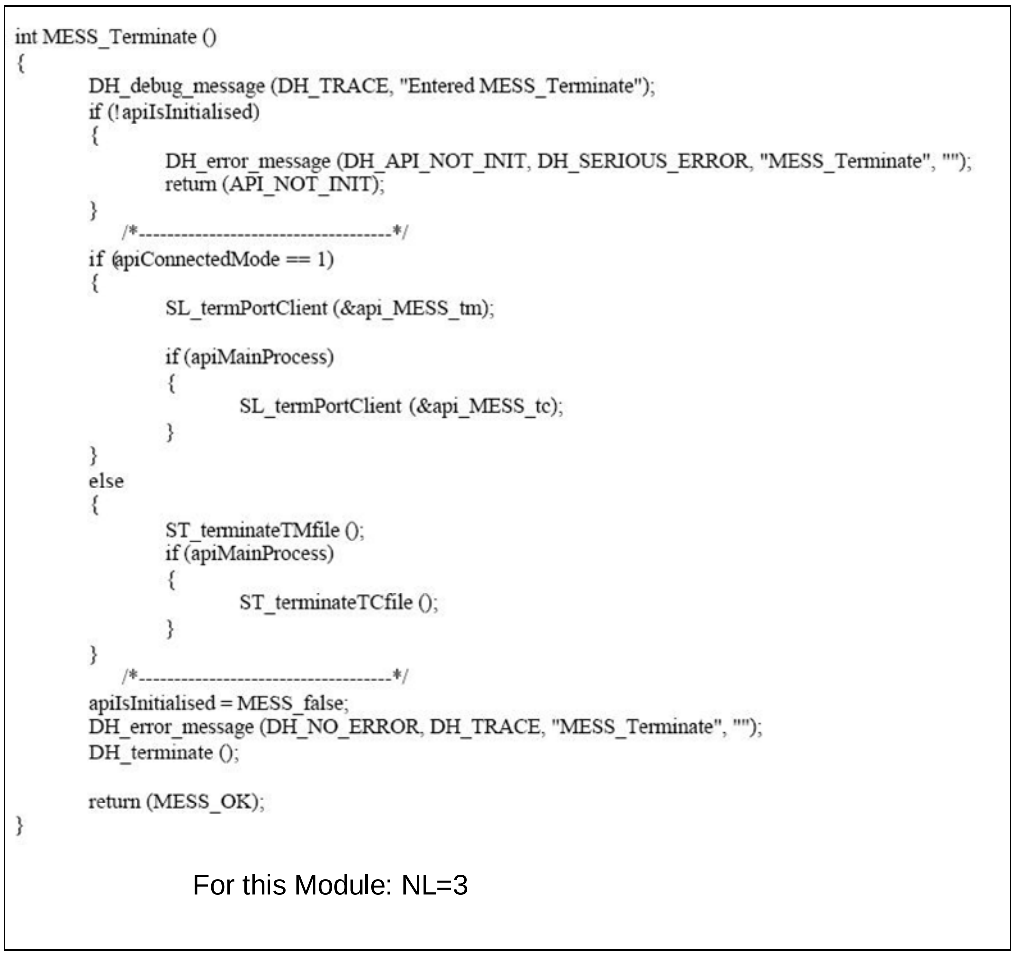
For this Module: VG=5

Figure A-3: Example of cyclomatic complexity

A.3.3.12 Nesting level

Main Characteristic	Maintainability
Sub Characteristic	Complexity
Metric name	Nesting level
Goal	This metric provides an indication of the code complexity, based on the depth of imbrications of the code.
Owner / Producer	Owner: development leader Producer: development team
Target audience	SW PA manager, development leader, V&V leader
Evaluation method	Static code analysis with the support of automatic tools.
Formula	The nesting level of a single routine (function or procedure) is defined as: NL = maximum number of nested statements (simple or multiple-choice decisions, loops) in the routine *(See sample computation in Figure A-4 below)* Then, the nesting level of a module is defined as: X = maximum NL for all routines in the module
Interpretation of measured value	In general, the lower the nesting level the more simple and more testable a software product is. However, too plain code might imply too complex design. Therefore, a good compromise should also be reached in this case. Proposed thresholds for the different criticality categories are: NL target value for A, B and C software: 5 NL target value for D software: 7 Further tailoring is also possible in terms of allowed exceptions to these thresholds (e.g. error-handling code).
Life cycle phase	<u>Collected</u> during SW validation and verification processes. <u>Provided</u> at CDR, and updated afterwards as required.
Applicability	- MANDATORY for criticality categories A to D.
Pre-conditions	- Coding activity finished (at least for a significant part of the product). - Availability of a static analysis tool (except maybe for small portions of assembler code).
Report format	- Tool dependant, but tabular and graphical results should both be provided (including summary figures). - Nesting level results can be presented at routine level or at module level.

Other remarks	- Remedial actions for modules/routines exceeding the threshold can be: redesign, code inspection, additional unit testing. - Nesting level and cyclomatic complexity values are very often highly coupled, but not always (they measure different kinds of complexity). - For programming languages where there is no separate exception block (e.g. ANSI C), error-handling code is believed to increase nesting level in an artificial way. In some cases this can be used as a justification for high nesting level values.



```
int MESS_Terminate ()
{
        DH_debug_message (DH_TRACE, "Entered MESS_Terminate");
        if (!apiIsInitialised)
        {
                DH_error_message (DH_API_NOT_INIT, DH_SERIOUS_ERROR, "MESS_Terminate", "");
                return (API_NOT_INIT);
        }
          /*-----------------------------------*/
        if (apiConnectedMode == 1)
        {
                SL_termPortClient (&api_MESS_tm);

                if (apiMainProcess)
                {
                        SL_termPortClient (&api_MESS_tc);
                }
        }
        else
        {
                ST_terminateTMfile ();
                if (apiMainProcess)
                {
                        ST_terminateTCfile ();
                }
        }
          /*-----------------------------------*/
        apiIsInitialised = MESS_false;
        DH_error_message (DH_NO_ERROR, DH_TRACE, "MESS_Terminate", "");
        DH_terminate ();

        return (MESS_OK);
}
```

For this Module: NL=3

Figure A-4: Example of nesting level

A.3.3.13 Lines of code (LOC)

Main Characteristic	Maintainability
Sub Characteristic	Complexity
Metric name	Lines of code
Goal	This metric provides an indication of the code complexity, based on the number of executable lines per routine.
Owner / Producer	Owner: development leader Producer: development team
Target audience	SW project manager, SW PA manager, development leader, V&V leader
Evaluation method	Static code analysis with the support of automatic tools.
Formula	LOC = (total number of lines of code) – (comment and blank lines)
Interpretation of measured value	This metric can be computed at routine level or at module level (by simple aggregation). In this Handbook, thresholds are proposed at routine level, as no limit is established for the number of routines per module. Proposed thresholds for the different criticality categories: LOC target value for A-C software: 50 LOC target value for D software: 75
Life cycle phase	<u>Collected</u> during SW validation and verification processes. <u>Provided</u> at CDR, and updated afterwards as required.
Applicability	- MANDATORY for criticality categories A to D.
Pre-conditions	- Coding activity finished (at least for a significant part of the product). - Availability of a static analysis tool (except maybe for small portions of assembler code).
Report format	Tool dependant, but tabular and graphical results should both be provided (including summary figures).
Other remarks	- There is some correlation between cyclomatic complexity and lines of code: high VG values imply often high LOC values; but not necessarily the opposite. - This metric is very often used to estimate effort in software projects (e.g. based on cost estimation models like COCOMO).

A.3.3.14 Comment frequency

Main Characteristic	Maintainability
Sub Characteristic	Complexity
Metric name	Comment frequency
Goal	This metric provides an indication of the legibility of the code in terms of percentage of comment lines.
Owner / Producer	Owner: SW PA manager Producer: development team
Target audience	SW PA manager, development leader
Evaluation method	Static code analysis with the support of automatic tools.
Formula	X= A/B, where: A = number of comment lines (excluding headers); B = LOC + (number of lines of comments) = total number of lines excluding blank lines
Interpretation of measured value	0 <= X <= 0.3 Proposed thresholds for the different criticality categories: Target value for criticality categories A to C: 0.3 Target value for criticality category D: 0.2 The metric can be collected at routine or module level. Proposed thresholds are applicable in both cases.
Life cycle phase	Collected during SW validation and verification processes. Provided at CDR, and updated afterwards as required.
Applicability	- MANDATORY for criticality categories A to D.
Pre-conditions	- Coding activity finished (at least for a significant part of the product). - Availability of a static analysis tool (except maybe for small portions of assembler code).
Report format	Tool dependant, but tabular and graphical results should both be provided (including summary figures).
Other remarks	- In modern programming, comment frequency is considered a poor indicator of legibility. Adherence to coding standards (naming conventions, programming rules) is considered a better alternative, although more expensive to reinforce and verify. - Remedial actions for modules/routines exceeding the threshold can be: code inspection to confirm whether additional comments are necessary or not. - If module/routine headers are included in this metric, then different thresholds should be established.

A.3.3.15 Requirement testability

Main Characteristic	Maintainability, Reliability
Sub Characteristic	Testability
Metric name	Requirement testability
Goal	This metric provides the percentage of requirements that are verified by test.
Owner / Producer	Owner: V&V leader Producer: V&V team
Target audience	SW PA manager, V&V leader, development leader
Evaluation method	Analysis of traceability matrices (i.e. requirements versus validation tests), eventually with the aid of some automatic tools (e.g. DOORS).
Formula	X = A/B, where: A = number of requirements verified by test; B = total number of requirements
Interpretation of measured value	0 <= X <= 1, the closer to 1 the better No generic target can be provided for this metric (it is application dependant), but a value below 80% should be a matter of concern.
Life cycle phase	Collected during SW validation and verification processes. Provided at PDR, and updated afterwards as required.
Applicability	- MANDATORY for criticality categories A to C - RECOMMENDED for criticality category D.
Pre-conditions	Availability of traceability matrices.
Report format	Textual (just a figure).
Other remarks	This metric can be applied at both RB and TS levels. This would allow analysing how the requirement testability evolves down to next lower level.

A.3.3.16 Modular span of control

Main Characteristic	Maintainability
Sub Characteristic	Modularity
Metric name	Modular span of control
Goal	This metric provides an indication of the number of subroutines that are called by the subroutine under consideration (similar to fan-out).
Owner / Producer	Owner: SW PA manager Producer: development team
Target audience	SW PA manager, development leader
Evaluation method	Static code analysis with the support of automatic tools.
Formula	There is no formula associated to this metric.
Interpretation of measured value	The modularity of the software product is the better the smaller the number of subroutines with a number of called subroutines that exceeds the agreed target value Proposed thresholds for the different criticality categories: MSC target value for A software: 2 MSC target value for B software: 5 MSC target value for C software: 7 MSC target value for D software: 9
Life cycle phase	<u>Collected</u> during SW design and implementation engineering and SW verification processes. <u>Provided</u> at CDR and updated afterwards as required
Applicability	- MANDATORY for criticality category A - RECOMMENDED for criticality categories B and C - OPTIONAL for criticality category D.
Pre-conditions	Source code is available. Source code inspection for conformance to the coding standard is carried out and documented Use of static analysis tools to support data collection is recommended
Report format	Tool dependant or textual figure per subroutine Table with the names of the subroutines, the corresponding unit name, the criticality category of the unit, the agreed maximum modular span of control value, the actually measured modular span of control value together with the list of called subroutines; short analysis identifying the number of non-justifiable subroutines with a modular span of control value higher than the agreed target value.
Other remarks	

A.3.3.17 Modular coupling

Main Characteristic	Maintainability
Sub Characteristic	Modularity
Metric name	Modular coupling
Goal	This metric provides an indication of the coupling of the modules
Owner / Producer	Owner: SW PA manager Producer: development team
Target audience	SW PA manager, development leader
Evaluation method	Manual code analysis (possibly with the support of an automatic tool).
Formula	$C = \text{Median}\ \{coup(D_i, D_j): 1 <= i < j <= n\}$ with $coup(x, y) = k + m/(m+1)$ with: n being the number of modules under consideration, k being the maximum of the numbers corresponding to the different types of coupling among modules x and y as outlined below, i.e. *0 No coupling relation: x and y have no communication.* *1 Data coupling relation: x and y communicate through parameters, where these are either single data elements or homogeneous set of data items that have no control elements* *2 Stamp coupling relation:x and y accept the same record type as a parameter.* *3 Control coupling relation: x passes a variable to y with the intention of controlling its actions.* *4 Common coupling relation: x and y refer to the same global data.* *5 Content coupling relation: x refers to the inside of y; hence it branches into, changes data in, or alters a statement in y* and m being the number of times the type of coupling among x and y with the highest ordinal number k is implemented (see Fenton and Melton, 1990)
Interpretation of measured value	The modularity of the software product is the better the smaller the metric result value. Proposed thresholds for the different criticality categories: A and B software: 3 C and D software: 4
Life cycle phase	Collected during SW design and implementation engineering and SW verification processes. Provided at CDR and updated afterwards as required
Applicability	- MANDATORY for criticality category A. - RECOMMENDED for criticality categories B, C. - OPTIONAL for criticality category D.

Pre-conditions	Source code is available. In the course of the software unit design phase, detailed information about the coupling to other software units is collected and documented (e.g. in the software unit design specification)
Report format	Table with the names of the software units, the criticality category of the unit, the agreed maximum modular coupling, the actually measured modular coupling value together with the list of software units that are coupled to the software unit under consideration and the respective coupling type
Other remarks	

A.3.3.18 Modular cohesion

Main Characteristic	Maintainability
Sub Characteristic	Modularity
Metric name	Modular cohesion
Goal	This metric provides an indication of the functions assigned to a single software module.
Owner / Producer	Owner: SW PA manager Producer: development team
Target audience	SW PA manager, development leader
Evaluation method	Manual code analysis (possibly with the support of an automatic tool).
Formula	C = Max {coh(D_i): 1<= i <= n} with coh(x) = k with: n being the number of modules under consideration, k being the ordinal value corresponding to the cohesion type valid for the module under consideration according to *0 Functional: the module carries out a specific well-defined function.* *1 Sequential: the module performs more than one function, but they happen in an order set out by a specification.* *2 Communicational: the module performs more than one function, but all on the same set of data.* *3 Procedural: the module carries out more than one function, and they are related only to a general procedure influenced by the software.* *4 Temporal: the module carries out more than one function, and they are linked only by the fact that they must happen in the same time period.* *5 Logical: the module carries out more than one function, and they are associated only logically.* *6 Coincidental: the module carries out more than one function, and they are not related.*

Interpretation of measured value	The modularity of the software product is the better the smaller the metric result value Proposed thresholds for the different criticality categories: A and B software: 2 C and D software: 3
Life cycle phase	<u>Collected</u> during SW design and implementation engineering and SW verification processes. <u>Provided</u> at CDR and updated afterwards as required
Applicability	- MANDATORY for criticality category A. - MANDATORY for criticality categories B and C - OPTIONAL for criticality category D.
Pre-conditions	Source code is available. In the course of the software unit design phase, detailed information about the coupling to other software units is collected and documented (e.g. in the software unit design specification)
Report format	Table with the names of the software units, the criticality category of the unit, the agreed maximum modular coupling, the actually measured modular coupling value together with the list of software units that are coupled to the software unit under consideration and the respective coupling type
Other remarks	

A.3.3.19 Process reliability adequacy

Main Characteristic	Reliability
Sub Characteristic	Reliability evidence
Metric name	Process reliability adequacy
Goal	This metric provides a subjective assessment of the adequacy of reliability activities to accomplish the SW reliability requirements
Owner / Producer	Owner: SW Project manager Producer: SW PA manager
Target audience	SW project manager, SW PA manager, development leader, V&V leader
Evaluation method	Checklist to assess to what extent the development takes into account reliability aspects
Formula	$X = A / B$ A = Number of selected checklist items supported by evidence B = Number of selected checklist items.
Interpretation of measured value	$0<=X<=1$, the closer to 1 the better The confidence in the reliability is the higher the more thoroughly the validity of the checklist items is substantiated by evidence.

Life cycle phase	Collected during SW requirements and architecture engineering, design and implementation engineering and SW verification and validation, Provided at SRR and updated afterwards as required
Applicability	- MANDATORY for criticality categories A,B and C - RECOMMENDED for criticality category D
Pre-conditions	"Reliability" requirements specified in the requirements baseline and the technical specification.
Report format	Table displaying for each selected checklist item the evidence that is supposed to cover that item.
Other remarks	

Table A-4: Checklist for process reliability adequacy

No	Question	Supporting Evidence	Mark (Y,N,NA)
1	The software requirements related to reliability are defined based on suitable and rigorous methods.		
2	The requirements baseline specifies the fault detection, identification, and recovery strategy to be implemented, and that the strategy is coherent with the dependability, security and safety level of the software under consideration.		
3	The technical specification includes all non-functional requirements necessary to satisfy the reliability requirements baseline.		
4	The quality level of the existing software is analysed with respect to the project requirements, according to the criticality of the system function implemented.		
5	The software dependability and safety analysis is based on a combination of well-established methods and techniques, to be performed at technical specification and design level, such as (ref. ECSS-Q-HB-80-03): software failure modes, effects and criticality analysis; software fault tree analysis; software common cause failure analysis.		
6	All results from the dependability analysis are taken into account in the definition of the technical specification.		
7	The results of SW safety and dependability analyses are used in order to determine the criticality of individual software components.		
8	Based on the results of the software criticality analysis, suitable engineering measures are applied o reduce the number of software critical components and mitigate the risks associated with the critical software.		

No	Question	Supporting Evidence	Mark (Y,N,NA)
9	Measures are defined and implemented to avoid propagation of failures between software components of different criticality.		
10	Measures to assure the reliability and dependability of critical software are defined and applied.		
11	Status of the implementation and verification of the software dependability and safety analysis recommendations is reported.		
12	Test are defined and executed according to the software module criticality category.		
13	The selected measures to handle critical components are properly verified.		
14	Robustness tests are planned and successfully carried out.		
15	Stress tests are planned and successfully carried out.		
16	Verification and validation activities are performed to verify that all dependability requirements have been satisfied and that all dependability recommendations have been considered.		
17	The SUM contains correct and complete information about features for FDIR in accordance to technical specification.		
18	ISVV activities are planned and identified, taking into account the outcomes of the SW dependability analysis, and define the ISVV activities to be performed. The ISVV activities include reviews, inspections, testing and audits.		
19	Recommendations from ISVV team are taken into account by the mainstream development team.		

A.3.3.20 Structural coverage

Main Characteristic	Reliability
Sub Characteristic	Reliability Evidence
Metric name	Structural coverage
Goal	This metric allows assessing whether the structural coverage requirements are met.
Owner / Producer	Owner: V&V leader Producer: V&V team
Target audience	SW PA manager, V&V leader, development leader
Evaluation method	Dynamic analysis of the code with the support of automatic tools.
Formula	X = A/B, where: A = number of executed statements/decisions/conditions; B = total number of statements/decisions/conditions;
Interpretation of measured value	*See table below for proposed target values depending on criticality category and coverage type.*
Life cycle phase	Collected during SW validation and verification processes. Provided at CDR, and updated afterwards as required.
Applicability	- MANDATORY for all criticality categories
Pre-conditions	- Coding activity finished (at least for a significant part of the product). - V&V activities at unit level properly planned and unit test cases and procedures available. - Availability of a dynamic analysis tool (except maybe for small portions of assembler code). - Unit testing regression strategy defined and implemented.
Report format	- Tool dependant, but tabular and graphical results should both be provided (including summary figures). - Structural coverage results can be presented at subroutine level or at module level (average for all routines in a given module).
Other remarks	- Very important metric, which can be directly mapped into one or more quality requirements. - The purpose of *functional test coverage* and *structural coverage* are different. One should not be used to justify the other. - *Unit test coverage* is sometimes referred too as the combination of structural coverage (by test) and manual coverage (by visual inspection). In that way, very demanding coverage requirements can be satisfied when some statements/paths are unreachable, or verification by test is too expensive for them.

Table A-5: Test coverage requirements

COVERAGE TYPE	CRITICALITY CATEGORY				
	A	B	C	D	
Statement Coverage (Source Code)	100 %	100 %	100 %	AM	
Statement Coverage (Object Code)	100%	AM	AM	AM.	
Decision Coverage (Source Code)	100%	100%	AM	AM.	
Modified Condition & Decision Coverage (Source Code)	100%	AM.	AM	AM.	
NOTE: "AM" means that the value is agreed with the customer and measured as per ECSS-Q-ST-80 clause 6.3.5.2.					

A.3.3.21 SPR/NCR status

Main Characteristic	Reliability
Sub Characteristic	Reliability evidence
Metric name	SPR/NCR status
Goal	This metric provides a snapshot of the SPR/NCR status at a given point in time, classified by SPR/NCR severity levels.
Owner / Producer	Owner: SW PA manager Producer: CM responsible
Target audience	SW project manager, SW PA manager, development leader, V&V leader, CM responsible
Evaluation method	Analysis of SPR/NCR database.
Formula	There is no formula associated to this metric.
Interpretation of measured value	- No major/critical SPR/NCR should remain open at SW-AR. - All minor SPRs/NCRs still open at SW-AR should be properly covered by temporary or permanent RFW.
Life cycle phase	<u>Collected</u> during SW verification and validation, SW delivery and acceptance, SW operation and SW maintenance processes. <u>Provided</u> at CDR and updated afterwards for each milestone or progress meeting.
Applicability	- MANDATORY for all categories
Pre-conditions	- SPR/NCR procedure defined and implemented. - A good policy to classify SPRs/NCRs by severity level (e.g. critical, major, minor) should be also in place. - SPR/NCR system should allow identifying those NCRs that are software-related. - Availability of supporting tools to analyse the SPR/NCR database is strongly recommended.
Report format	SPR/NCR table with summary figures at the end (e.g. total number of raised, analysed, implemented, tested, closed).
Other remarks	Only software-related NCRs are considered.

A.3.3.22 Environmental software independence

Main Characteristic	Maintainability, Reusability
Sub Characteristic	Portability
Metric name	Environmental software independence
Goal	This metric provides an indication of the degree of independence of the SW product from its software environment (such as operating system or external libraries).
Owner / Producer	Owner: SW PA manager Producer: development team, V&V team
Target audience	SW PA manager, development leader, V&V leader
Evaluation method	- Analysis of the design documentation, eventually with the help of an automatic tool. - Identification of those design components including external calls (e.g. to operating system or external libraries routines) or using external data.
Formula	X= A/B, where: A = number of design components expected to maintain their correct behaviour in a different software environment; B = total number of design components
Interpretation of measured value	0 <= X <= 1, the closer to 1 the better Target value for levels A to C: 0.95 Target value for level D: 0.90
Life cycle phase	<u>Collected</u> during SW design and implementation engineering process. <u>Provided</u> at DDR and updated afterwards as required.
Applicability	- MANDATORY for criticality categories A to C. - RECOMMENDED for criticality category D.
Pre-conditions	- Availability of design documentation, with a level of detail sufficient to identify external calls and data. - Use of a supporting tool is highly recommended.
Report format	Tool dependant. For example, a cross matrix identifying all external dependencies for each design component.
Other remarks	The notion of design component can vary from project to project (e.g. HOOD terminal object, UML class).

A.3.3.23 System hardware independence

Main Characteristic	Maintainability, Reusability
Sub Characteristic	Portability
Metric name	System hardware independence
Goal	This metric provides an indication of the degree of independence of the SW product from its hardware environment.
Owner / Producer	Owner: SW PA manager Producer: development team, V&V team
Target audience	SW PA manager, development leader, V&V leader
Evaluation method	- Analysis of the design documentation, eventually with the help of an automatic tool. - Identification of those design components including direct interface with hardware.
Formula	X= A/B, where: A = number of design components expected to maintain their correct behaviour in a different hardware environment; B = total number of design components
Interpretation of measured value	0 <= X <= 1, the closer to 1 the better Target value for level A: 0.95 Target value for level B: 0.90 Target value for levels C and D: 0.85
Life cycle phase	Collected during SW requirements and architecture engineering, SW design and implementation engineering processes. Provided at PDR and updated afterwards as required.
Applicability	- MANDATORY for criticality categories A to C. - RECOMMENDED for criticality category D.
Pre-conditions	- Availability of HW/SW ICD and high-level design documentation with a level of detail sufficient to identify individual components interfacing with hardware. - Use of a supporting tool is highly recommended.
Report format	List of design components including direct interface with hardware, including summary figures.
Other remarks	It is expected that the software part interfacing with hardware is isolated in a low-level design layer, which is then used by other higher-level design components. This is why the target values for this metric are quite strict.

A.3.3.24 Reusability checklist

Main Characteristic	Reusability
Sub Characteristic	Reusability documentation
Metric name	Reusability checklist
Goal	This metric provides a subjective assessment of the reuse potential based on the quality of the development and V&V documentation.
Owner / Producer	Owner: SW PA manager Producer: development team, V&V team
Target audience	SW PA manager, development leader, V&V leader
Evaluation method	Reusability checklist *(see sample checklist below)*
Formula	X = A/B, where: A = sum of Yes or N/A answers to the questions in the checklist B = total number of questions
Interpretation of measured value	The measured value should be 100% (i.e. all questions either positively answered or found not applicable). No specific target value identified for each criticality category.
Life cycle phase	Collected from system engineering process. Provided at SRR, and updated afterwards as required.
Applicability	- MANDATORY for all criticality categories.
Pre-conditions	- Availability of the relevant documentation. - Availability of team members to answer the checklist.
Report format	Answered checklist.
Other remarks	This metric becomes OPTIONAL if there are not 'reuse' requirements in the project.

Table A-6: Sample checklist for reusability checklist

No	Question	Supporting Evidence	Mark (Y,N,NA)
1	Re-use related requirements are specified.		
2	The procedures, methods and tools for reuse are specified and applied to the software engineering processes to comply with the reusability requirements for the software development.		
3	Maintainability, portability and verification requirements (for software to be re-used) are specified in the technical specification.		
4	Dependability on the environmental software and on the environmental hardware is minimized (relative to the project constraints), described and justified.		
5	If the software is intended for re-use and is executed on multiple hardware platforms, reliable evidences should be		

No	Question	Supporting Evidence	Mark (Y,N,NA)
	provided that the corresponding validation tests have been carried out on all specified hardware platforms.		
6	The application conditions for the software intended for re-use are specified (i.e. all information necessary for the future decision making process whether the software is fit for the project specific purpose, e.g. the criticality of the corresponding software components).		
7	Specific design requirements are applied if the software is to be designed for intended reuse.		
8	The detail design specifies for each software component, whether it is intended for re-use or not.		
9	The software is designed such that mission and configuration dependant data are separated (e.g. in a database).		
10	If the software is written for the reuse, the design provides its provided functionality from an external point of view and its external interfaces.		
11	Reusability limitations (e.g. due to a low criticality category) are defined.		
12	The configuration management system takes account the specific aspects of software developed for intended reuse, such as longer lifetime of these components as compared to other components of the project, evolution or change of the development environment for the projects that intend to use the components, and transfer of the configuration and documentation management information to these projects.		
13	Justification of methods and tools of the design for re-use is provided.		
14	The information related to components developed for intended reuse is separated from others (in the technical specification, the design justification file, the design definition file and the product assurance file).		
15	The Software Reuse File describes the technical and management information available on the software intended for reuse.		
16	The Software Reuse File documents the results of the software reuse analysis.		
17	Assumptions and methods applied when estimating the level of reuse are provided in the Software Reuse File.		
18	Corrective actions identified to ensure that the software intended for reuse meets the applicable project requirements and its implementation are documented in the Software Reuse File.		

No	Question	Supporting Evidence	Mark (Y,N,NA)
19	The Software Reuse File includes the detailed configuration status of the reused software baseline.		
20	The design for re-use organization and the content of the user manual or equivalent document helps people in re-using software.		
21	The analysis of the potential reusability of existing software components is performed through: 1. identification of the reuse components and models with respect to the functional requirements baseline, and; 2. a quality evaluation of these components.		
22	An evaluation of the reuse potential of the software is performed.		
23	Analyses of the advantages obtained with the selection of existing software instead of new development are carried out.		
24	Justification of re-use with respect to requirements baseline is provided.		
25	Specific constraints induced by reused software (e.g. COTS, free software and open source) are specified.		
26	For each software item, the estimated level of reuse and the assumptions and methods applied when estimating the level of reuse are provided.		
27	List of reuse components is provided.		
28	The re-use related software acquisition process is defined and implemented.		
29	The design describes how to handle the existing reused components.		
30	Reverse engineering techniques are applied to generate missing documentation and to reach the required verification and validation coverage.		
31	For software products whose life cycle data from previous development are not available and reverse engineering techniques are not fully applicable, the following methods are applied: 1. generation of validation and verification documents based on the available user documentation (e.g. user manual) and execution of tests in order to achieve the required level of test coverage; 2. use of the product service history to provide evidence of the product's suitability for the current application.		

A.3.3.25 Reuse modification rate

Main Characteristic	Reusability
Sub Characteristic	Reuse Modification
Metric name	Reuse modification rate
Goal	This metric keeps track of the amount of estimated and/or performed modifications applied to every existing software component.
Owner / Producer	Owner: SW PA manager Producer: development team, V&V team
Target audience	SW PA manager, development leader, V&V leader
Evaluation method	Static code analysis
Formula	X = NLOC MO/LOC, where: NLOC MO= total number of estimated or actually modified/added lines of existing software LOC= total lines of code of the existing software
Interpretation of measured value	- This metric gives a guideline for assessing what extent modifications can be made before needing to treat the existing software as an entirely new software product to be developed. - The ratio of modified/added lines of code should be lower or equal than the estimated % of software modification. - If the ratio is greater that the estimated % of modifications, then the software is considered as new software. - No specific target value is identified for the estimated % of code modified for each criticality category. They are strictly project dependant Example: up to an estimated 20% of source code modified/added is to be considered reuse software.
Life cycle phase	<u>Collected</u> from system engineering process. <u>Provided</u> at SRR, and updated afterwards as required.
Applicability	- MANDATORY for all criticality categories.
Pre-conditions	Availability of the source code.
Report format	Graphical chart (KLOC modified - %modified)
Other remarks	

A.3.3.26 Safety activities adequacy

Main Characteristic	Suitability for Safety
Sub Characteristic	Safety Evidence
Metric name	Safety activities adequacy
Goal	This metric provides a subjective assessment of the adequacy of the safety activities performed in the project.
Owner / Producer	Owner: SW PA manager Producer: development team, V&V team
Target audience	SW PA manager, development leader, V&V leader
Evaluation method	Safety checklist *(see sample checklist below)*
Formula	X = A/B, where: A = sum of Yes or N/A answers to the questions in the checklist B = total number of questions
Interpretation of measured value	The measured value should be 100% (i.e. all questions either positively answered or found not applicable). No specific target value identified for each criticality category.
Life cycle phase	Collected from system engineering process. Provided at SRR, and updated afterwards as required.
Applicability	- MANDATORY for criticality categories A to B. - RECOMMENDED for criticality category C. - OPTIONAL for criticality category D.
Pre-conditions	- Availability of the relevant safety material. - Availability of team members to answer the checklist.
Report format	Answered checklist.
Other remarks	- The proposed checklist covers three areas: safety planning, safety analysis and safety techniques. - The proposed target values might seem quite strict, but this is not the case: For the lower criticality categories the answer to most questions is probably N/A. - This metric is only applicable if there are safety-related requirements in the project.

Table A-7: Sample checklist for safety activities adequacy

No	Question	Supporting Evidence	Mark (Y,N,NA)
1	Definition of the SW safety activities as part of the Software product assurance plan, specifying activities to be carried out, the implementation schedule and the resulting products.		
2	Software safety responsibilities are identified.		
3	ISVV activities are planned and identified, taking into account		

No	Question	Supporting Evidence	Mark (Y,N,NA)
	the outcomes of the SW safety analysis, and define the ISVV activities to be performed. The ISVV activities include reviews, inspections, testing and audits.		
4	Evidences that the software requirements (at TS level) cover the safety requirements (at RB level) completely and appropriately are provided.		
5	Definition of SW safety requirements (involving analysis of system safety requirements, hardware, software and user interfaces, and areas of system performance) are provided.		
6	Safety analyses at the SW requirements phase are performed to identify hazards and possible incorrect assignment of safety requirements to the software and consequent enhancement of the TS, coding and testing by safety recommendations.		
7	SW safety requirements are allocated into SW design.		
8	Safety analysis are performed at SW design and implementation phases to identify hazards and possible incorrect assignment of safety requirements to the software; and consequent enhancement of the TS, coding and testing by safety recommendations.		
9	Verification and validation activities are performed to verify that all safety requirements have been satisfied and that all safety recommendations have been considered.		
10	Recommendations from ISVV team are taken into account by the mainstream development team.		
11	Means are defined to receive feedback from the upper level safety representative regarding possible safety impact of SPRs/NCRs and derived requirements properly identified.		
12	Verification that the above identified processes are properly applied is performed.		
13	Measures that increase the safety of the software are incorporated into the design or implementation (e.g. safe subset of programming languages, use of formal or semi-formal methods, definition of a safe state, etc.).		
14	The code implements safety requirements based on suitable methods and measures used.		
15	It is ensured that the code is controlling any possible software contribution to system hazardous events.		

A.3.3.27 Security checklist

Main Characteristic	Security
Sub Characteristic	Security Evidence
Metric name	Security checklist
Goal	This metric provides a subjective assessment of the adequacy of the security activities performed in the project.
Owner / Producer	Owner: SW PA manager Producer: development team, V&V team
Target audience	SW PA manager, development leader, V&V leader
Evaluation method	Security checklist
Formula	X = A/B, where: A = sum of Yes or N/A answers to the questions in the checklist B = total number of questions
Interpretation of measured value	The measured value should be 100% (i.e. all questions either positively answered or found not applicable). No specific target value identified for each criticality category.
Life cycle phase	Collected from system engineering process. Provided at SRR, and updated afterwards as required.
Applicability	- MANDATORY for all criticality categories.
Pre-conditions	- Availability of the relevant security material. - Availability of team members to answer the checklist.
Report format	Answered checklist.
Other remarks	This metric is only applicable if there are security requirements in the project.

Table A-8: Checklist for security checklist

No	Question	Supporting Evidence	Mark (Y,N,NA)
1	The requirement baseline covers all project relevant information that is necessary to specify security related software requirements (on technical specification level).		
2	A systematic security analysis (to identify potential security problems) has been carried out, the results are documented and have been used to specify the security related software requirements on the technical specification level.		
3	Software security responsible is identified.		
4	A security level is assigned to each SW item, according to project security criteria.		
5	Security procedures are defined and applied to handle SW items at each security level.		

No	Question	Supporting Evidence	Mark (Y,N,NA)
6	Verification that the above identified procedures are properly applied is performed.		
7	The security related software requirements (technical specification level) are sufficient to cover the security related information specified in the requirements baseline.		
8	All user interfaces (for installation, for operation, for maintenance, for updates, etc.) are specified in a self-contained manner and have each got assigned a security level (specifying the criticality with regards to security).		
9	Access to critical user interfaces (security) is limited by individual accounts that are secured against misuse by a password.		
10	An appropriate guideline for the selection of a suitable password is available (e.g. length of the password, usage of special characters, etc.).		
11	An appropriate guideline for the "superuser" responsibilities and interfaces to the software is available (e.g. for account and password management).		
12	The software design is justified (e.g. encapsulation of security relevant software components).		
13	Methods to ensure integrity, availability and confidentiality of data have been defined and implemented.		
14	Verification and validation activities are performed to verify that all security requirements have been satisfied and that all security recommendations have been considered.		
15	The assignment of database read/write rights (to software units) have been reviewed for security related impacts.		
16	All activities carried out under a (security) critical account are logged such that the integrity of the logging files is ensured.		
17	Possible security flaws (i.e. security related abnormal conditions on software unit level) have been specified based on experience and on a systematic approach.		
18	Each identified security flaw has got assigned a justified counter measure (to be applied by the coder), spot checks are recommended.		
19	The software has been analyzed by a specialist (e.g. a vulnerability analyst) to identify not yet covered security flaws in the software.		

A.3.3.28 User documentation clarity

Main Characteristic	Usability, Maintainability
Sub Characteristic	User documentation quality
Metric name	User documentation clarity
Goal	This metric provides an indication of the quality of the user documentation.
Owner / Producer	Owner: SW PA manager Producer: development team
Target audience	SW PA manager, development leader
Evaluation method	Analysis of user documentation, eventually with the aid of some automatic tools.
Formula	X= A/B, where: A= number of ambiguous statements within the user documentation; B= total number of statements within the user documentation
Interpretation of measured value	0 <= X <= 1, the closer to 0 the better
Life cycle phase	Collected during SW design and implementation engineering, SW verification and validation processes. Provided at CDR, and updated afterwards as required.
Applicability	- RECOMMENDED for all criticality categories.
Pre-conditions	- Availability of user documentation. - Use of supporting tools is strongly recommended.
Report format	Tool dependant.
Other remarks	For the purpose of this metric, a sentence is defined as a group of words containing a subject, a verb and expressing a complete thought. Sentences can be identified counting the full stops ".".

A.3.3.29 User documentation completeness

Main Characteristic	Usability, Maintainability
Sub Characteristic	User documentation quality
Metric name	User documentation completeness
Goal	This metric provides the number of remaining open points in the user documentation.
Owner / Producer	Owner: SW PA manager Producer: development team
Target audience	SW PA manager, development leader
Evaluation method	Analysis of user documentation, eventually with the aid of automatic tools (e.g. macros).
Formula	X= A/B, where: A= number of sections containing TBCs/TBDs; B= total number of sections;
Interpretation of measured value	0 <= X <= 1, the closer to 0 the better
Life cycle phase	<u>Collected</u> during SW design and implementation engineering, SW verification and validation processes. <u>Provided</u> at CDR, and updated afterwards as required.
Applicability	- RECOMMENDED for all criticality categories.
Pre-conditions	- Availability of user documentation. - Use of a supporting tool is highly recommended.
Report format	TBC/TBD table as an annex to the relevant document (including summary figures).
Other remarks	The metric does not take into consideration the *relevance* of each TBC/TBD (otherwise it would become too complicate to be collected). It just provides an *indication* of the number of open points.

A.3.3.30 User manual suitability

Main Characteristic	Usability, Maintainability
Sub Characteristic	User documentation quality
Metric name	User manual suitability
Goal	This metric provides a subjective indication of the suitability of the user manual.
Owner / Producer	Owner: SW PA manager Producer: development team
Target audience	SW PA manager, development leader
Evaluation method	Application of a user manual suitability checklist.

Formula	X= A/B, where: A = sum of Yes or N/A answers to the questions in the checklist B = total number of questions
Interpretation of measured value	The measured value should be 100% (i.e. all questions either positively answered or found not applicable)
Life cycle phase	Collected during SW requirements and architecture engineering, SW design and implementation engineering, SW verification and validation processes. Provided at CDR, and updated afterwards as required.
Applicability	- MANDATORY for all criticality categories.
Pre-conditions	- Availability of the user manual. - Availability of team members to answer the checklist.
Report format	Answered checklist
Other remarks	

Table A-9: Checklist for User manual suitability

No	Question	Supporting Evidence	Mark (Y,N,NA)
1	The user manual reports an overview of the system.		
2	Each operation is described in the user manual.		
3	Cautions and warning are described in the user manual.		
4	For each operation the user manual provides: - set-up and initialisation; - input operations; - what results to expect.		
5	Probable errors and possible causes are provided.		
6	The user manual reports error messages and recovery procedures.		
7	The maintenance process and the activities to be carried out by the user are described.		
8	The fault reporting process and the activities to be carried out by the user are.		
9	The parameterization capabilities of the software are described.		
10	The application conditions of the software (i.e. constraints that are necessary for a requirement conformant program execution) are described.		
11	Help desk information (in form of a phone number, of an E-mail address, etc.) is sufficiently detailed.		

A.3.3.31 Adherence to MMI standards

Main Characteristic	Usability
Sub Characteristic	Understandability
Metric name	Adherence to MMI standards
Goal	This metric provides a subjective assessment of the adherence to the applicable MMI standards.
Owner / Producer	Owner: SW PA manager Producer: development team
Target audience	SW PA manager, development leader
Evaluation method	MMI standards checklist, to be filled in with the help of static analysis tools. - Rules covered by automatic tools are expected to be verified for 100% of the code. - Sample code size should be specified for those rules to be verified manually (at least 5% of the code should be inspected). - No sample checklist is provided because this is strictly project/company dependant.
Formula	X = A/B, where: A = sum of Yes or N/A answers to the questions in the checklist B = total number of questions
Interpretation of measured value	The measured value should be 100% (i.e. all questions either positively answered or found not applicable). No specific target value identified for each criticality category.
Life cycle phase	Collected during SW validation and verification processes. Provided at CDR, and updated afterwards as required.
Applicability	- MANDATORY for criticality categories A to D.
Pre-conditions	- Availability of the relevant documentation. - Availability of team members to answer the checklist. - Use of static analysis tools to support data collection is strongly recommended.
Report format	- Static analysis reports (textual and graphic, tool dependant). - Answered checklist for each manually inspected module.
Other remarks	- Even if no specific target values are identified (i.e. all applicable questions should be answered for the inspected modules), tailoring of this metric is possible from the point of view of sample code size. - Code size is not necessarily measured in LOC (lines of code) for this metric. A different unit of measure can be used for MMI applications (e.g. number of windows, buttons, menu choices).

A.3.3.32 Process assessment [ECSS-HB-Q-80-02]

Main Characteristic	Software Development Effectiveness
Sub Characteristic	Project development process level
Metric name	Process assessment
Goal	This metric provides the capability levels of those software processes that are applicable to the current project.
Owner / Producer	Owner: SW PA manager Producer: customer or third-party assessor
Target audience	Project manager, SW PA manager, others (depending on the assessed processes).
Evaluation method	[ECSS-HB-Q-80-02] assessment (or equivalent)
Formula	Assessment performed according to [ECSS-HB-Q-80-02] method
Interpretation of measured value	*See ECSS-Q-HB-80-02 for recommended target capability levels depending on the SW criticality category.*
Life cycle phase	The assessment should be conducted before the actual processes start, in order to detect possible gaps with the required levels and solve them. E.g. SW design and SW construction processes should be assessed before the SW design & implementation engineering process starts.
Applicability	- MANDATORY for criticality categories A-B. - RECOMMENDED for criticality categories C-D.
Pre-conditions	Availability of data to perform the assessment of the relevant processes (either from previous similar projects or from current project).
Report format	Assessment report according to [ECSS-HB-Q-80-02] method.
Other remarks	A process improvement program should be initiated to cover the gaps between the required capability levels and the measured capability levels (if any). Should this be the case, a re-assessment of the concerned processes should be performed after some time, in order to measure the results of the improvement program.

A.3.3.33 Milestone tracking

Main Characteristic	Software Development Effectiveness
Sub Characteristic	Project management effectiveness
Metric name	Milestone tracking
Goal	This metric provides a graphical representation of planned milestones versus achieved milestones over time.
Owner / Producer	Owner: project management Producer: project management
Target audience	Project manager, SW PA manager, development leader
Evaluation method	Analysis of project management data

Formula	For each project milestone, both planned and actual dates should be provided.
Interpretation of measured value	For each project milestone, the closer the actual date is to the planned date, the better.
Life cycle phase	Collected before every progress meeting. Provided with every progress report.
Applicability	- MANDATORY for all criticality categories
Pre-conditions	Project management data should be available and accessible
Report format	Results should be presented in a graphical manner (e.g. bar chart, progress chart), so the actual date can be compared with the expected one, for each milestone. *(See sample graphic below)*
Other remarks	Possible variations of this metric: In case of major schedule modifications, both the *initial planned date* and the *current planned date* should be collected (for each milestone). In case of significant gap between *provisional achievement* (i.e. successful pending of closure of all identified actions) and *final close-out* of a given milestone, both dates should be indicated as well.

A.3.3.34 Effort tracking

Main Characteristic	Software Development Effectiveness
Sub Characteristic	Project management effectiveness
Metric name	Effort tracking
Goal	This metric provides a graphical representation of estimated effort versus actually spent effort over time.
Owner / Producer	Owner: project management Producer: project management
Target audience	Project manager, project controller
Evaluation method	Analysis of project management data
Formula	For each ongoing or completed task, both the estimated and the actual effort figures should be provided.
Interpretation of measured value	For each task, the closer the actual spent effort is to the estimated effort, the better.
Life cycle phase	As a minimum: - Collected before every progress meeting. - Provided with every progress report.
Applicability	- MANDATORY for all criticality categories
Pre-conditions	Project management data should be available and accessible

Report format	Results should be presented in a graphical manner (e.g. bar chart, progress chart), so the actual spent effort can be compared with the expected one, for each task.
Other remarks	In case of major changes in effort estimations (e.g. due to change requests), both the *initial estimated effort* and the *current estimated effort* should be collected (for each related task).

A.3.3.35 Code size stability

Main Characteristic	Software Development Effectiveness
Sub Characteristic	Project management effectiveness
Metric name	Code size stability
Goal	This metric gives a graphical representation of estimated code size versus actual code size over time.
Owner / Producer	Owner: development leader Producer: development team
Target audience	SW project manager, SW PA manager, development leader, V&V leader
Evaluation method	Static code analysis with the support of automatic tools.
Formula	For each major design component, both estimated code size and actual code size should be provided.
Interpretation of measured value	The lower the gap between estimated code size and actual size the better.
Life cycle phase	Collected during SW design and implementation engineering process. Provided at DDR (estimations only) and then updated for each progress meeting or milestone with actual data.
Applicability	- MANDATORY for all criticality categories
Pre-conditions	- Detailed design activity finished (for estimations). - Coding activity started (for actual data). - Availability of a static analysis tool (except maybe for small portions of assembler code).
Report format	Results should be presented in a graphical manner (e.g. bar chart, progress chart), so the actual code size can be compared with the estimated one, for each design component. *(See sample graphic below)*
Other remarks	- Moderate increases with respect to estimations are quite common, even with fairly stable requirements. But differences larger than 20% between estimated and actual values should be investigated. - In case of major changes in size estimations (e.g. due to change requests), both the *initial estimated size* and the *current estimated size* should be collected (for each affected design component).

A.3.3.36 Requirement stability

Main Characteristic	Software development effectiveness
Sub Characteristic	Project management effectiveness
Metric name	Requirement stability
Goal	This metric provides an indication of the stability of requirements (at both RB and TS levels) in terms of added/modified/deleted requirements over time.
Owner / Producer	Owner: SW PA manager Producer: development team
Target audience	SW PA manager, development leader
Evaluation method	Analysis of requirements documents (SRD, ICDs), eventually with the aid of some automatic tools (e.g. DOORS).
Formula	$X = N/T$ $Y = M/T$ $Z = D/T$, where: N = number of added requirements since last version; M = number of modified requirements since last version; D = number of deleted requirements since last version; T = total number of requirements The global metric is then computed as an aggregation of X+Y+Z.
Interpretation of measured value	The lower the metric value the better. However, no target values are proposed for this metric because the reasons for high requirement volatility are strictly project dependant, and no generic thresholds that are valid for all situations can be established.
Life cycle phase	Collected during all development phases of the project. Provided at SRR, and updated regularly for each milestone until the SW-AR.
Applicability	- MANDATORY for criticality categories A to C. - RECOMMENDED for criticality category D.
Pre-conditions	- Availability of requirements documents. - Use of supporting tools is strongly recommended.
Report format	Tool dependant. Both textual and graphic representations are possible *(see examples below)*.
Other remarks	- A high requirements volatility rate might require adjustment of schedule and effort estimations. - Some system and software engineering processes should be reviewed, if the reason for this high volatility is not fully understood.

SW Version	Total number of existing requirements B	Number of changed/pnd requirements A	Requirement Stability
V1	30	0	0
V2	35	10	0.28
V3	40	5	0.13

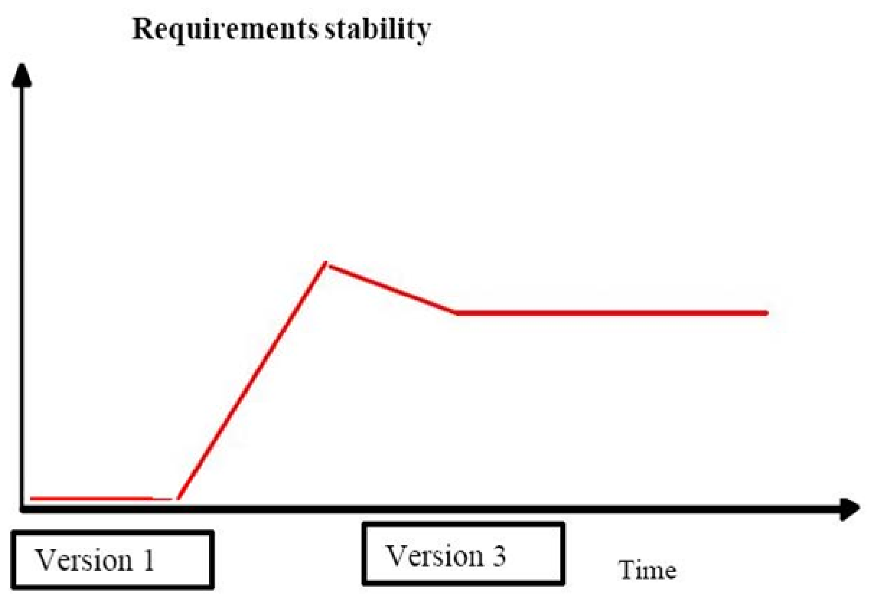


Figure A-5: Sample of requirements stability

A.3.3.37 RID/action status

Main Characteristic	Software Development Effectiveness
Sub Characteristic	Project management effectiveness
Metric name	RID/action status
Goal	This metric provides a snapshot of the RID/action status at a given point in time, classified by relevance (major, minor).
Owner / Producer	Owner: SW PA manager Producer: CM responsible
Target audience	SW project manager, SW PA manager, development leader, V&V leader, CM responsible
Evaluation method	Analysis of RID/action database.
Formula	There is no formula associated to this metric.

Interpretation of measured value	- No major RID from previous milestones should remain open at next milestone. - All RIDs/actions still open at SW-AR should be declared as 'open work' and a proper action plan to close them should be agreed with the customer.
Life cycle phase	<u>Collected</u> during all life cycle phases. <u>Provided</u> at SRR and updated afterwards for each milestone or progress meeting.
Applicability	- MANDATORY for all criticality categories.
Pre-conditions	- RID/action management procedures and tools in place. - A good policy to classify and handle major/minor RIDs/actions should be also in place.
Report format	RID/action status table with summary figures at the end (e.g. total number of issued, on-going, closed with/without action). *See sample graphic below.*
Other remarks	

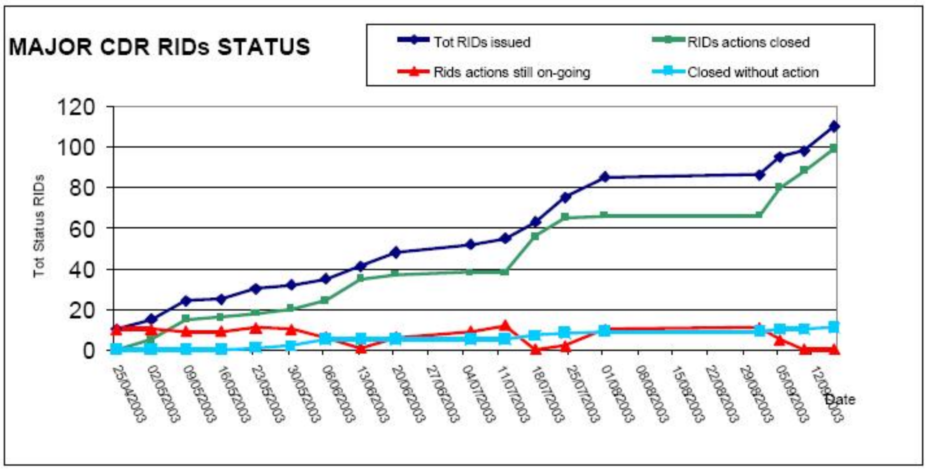


Figure A-6: Sample of RID/action status

A.3.3.38 V&V progress

Main Characteristic	Software development effectiveness
Sub Characteristic	Project management effectiveness
Metric name	V&V progress
Goal	This metric gives a graphical representation of planned V&V activities versus completed V&V activities over time.
Owner / Producer	Owner: V&V leader Producer: V&V team
Target audience	SW project manager, SW PA manager, V&V leader, development leader

Evaluation method	Analysis of SW V&V progress data or reports (when properly updated).
Formula	X = A/B, where: A = number of successfully completed V&V activities; B = number of planned V&V activities at this time
Interpretation of measured value	0 <= X <= 1, the closer to 1 the better No specific target value for each criticality category.
Life cycle phase	<u>Collected</u> during SW validation and verification processes. <u>Provided</u> at PDR, and updated afterwards as required.
Applicability	- MANDATORY for all criticality categories
Pre-conditions	Availability of relevant V&V progress data.
Report format	*See example below.*
Other remarks	This metric can be used to estimate the date of completion of the different V&V phases.

Internal Verifications note book

Planned Verification	Expected Execution Date	Last Execution Date	Result
VAL1	2/09/04	6/10/04	Succesfull
VAL2	15/08/04		Suspended
VALi	20/08/04	7/10/04	No successful
VALn	3/02/05		Planned

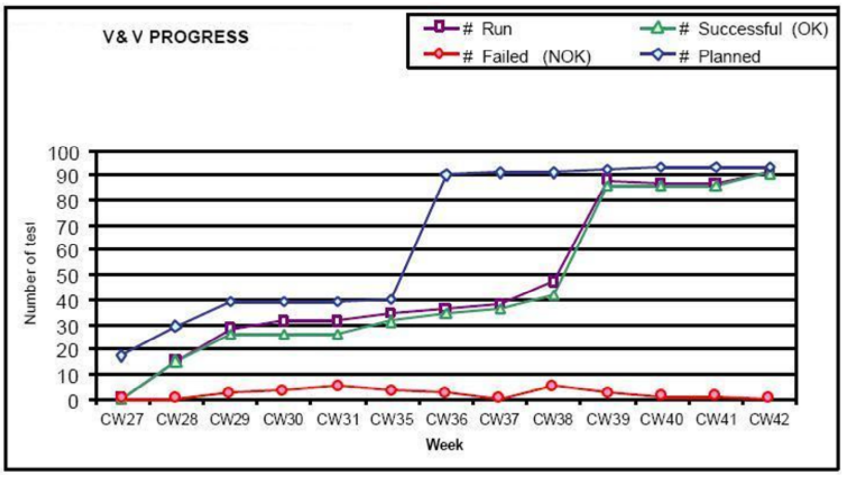


Figure A-7: Sample of V&V progress

A.4 List of proposed OO metrics

A.4.1 Introduction

This subclause provides a detailed description of a set of OO metrics proposed to measure some of the above presented characteristics and sub-characteristics as an alternative to the classic metrics (i.e. modular span of control), which are not considered appropriate for an object-oriented design.

The list of proposed OO metrics is not exhaustive. What is proposed here is a realistic small set of OO metrics found as more used in space projects. The thresholds provided here are not exact, but quite precise since, although they are taken from literature, they haven been confirmed later by practical application on real projects.

Within the quality model at hand, the following five additional metrics have been selected:

— Number of children (NOC)

— Depth of inheritance tree (DIT)

— Parametric Polymorphism factor (PPF)

— Coupling between objects (CBO)

— Lack of cohesion of methods (LOCM).

With the evaluation of these metrics, the following aspects are covered:

— Inheritance (NOC, DIT)

— Polymorphism (PPF)

— Modularity (CBO, LOCM).

A.4.2 Detail description of the proposed OO metrics

A.4.2.1 Number of children

Main Characteristic	Maintainability
Sub Characteristic	Analyzability
Metric name	Number of children (NOC)
Goal	To assess the degree of complexity induced by inheritance. The number of children is the number of immediate subclasses subordinate to a class in the hierarchy. It is an indicator of the potential influence a class can have on the design and on the system
Owner / Producer	Owner: development leader Producer: development team
Target audience	SW PA Manager, development leader, V&V leader
Evaluation method	Static code analysis with the support of automatic tools.
Formula	No Formula

Interpretation of measured value	NOC<= 4 The larger the number of children of a class, the greater is the possible impact arising from a modification of that class. The greater the number of children, the greater the likelihood of improper abstraction of the parent and may be a case of misuse of subclassing. But the greater the number of children, the greater the reuse since inheritance is a form of reuse.
Life cycle phase	Collected during design and implementation engineering, SW validation and verification processes. Provided at CDR, and updated afterwards as required.
Applicability	- MANDATORY for categories A-B-C - RECOMMENDED for criticality category D
Pre-conditions	Coding activity finished Availability of a static analysis tool.
Report format	Tool dependant, but tabular and graphical results should both be available. Table with the names of the classes, the criticality category of the class and the actually measured value. Remarks on classes with a large NOC value
Other remarks	If a class has a large number of children, it may require more testing of the methods of that class, thus increase the testing time. Remedial actions for classes with a large NOC value can be: redesign, code inspection, additional low level testing.

A.4.2.2 Depth of inheritance tree

Main Characteristic	Maintainability
Sub Characteristic	Analyzability
Metric name	Depth of inheritance tree (DIT)
Goal	To assess the degree of complexity induced by inheritance
Owner / Producer	Owner: development leader Producer: development team
Target audience	SW PA Manager, development leader, V&V leader
Evaluation method	Static code analysis with the support of automatic tools.
Formula	No Formula
Interpretation of measured value	DIT <= 4 The larger the maximum length of a chain of inheritance the more complex is the software. The deeper a class is within the hierarchy, the greater the number methods it is likely to inherit making it more complex to predict its behaviour.

Life cycle phase	Collected during design and implementation engineering, SW validation and verification processes. Provided at CDR, and updated afterwards as required.
Applicability	- MANDATORY for criticality categories A-B-C - RECOMMENDED for criticality category D
Pre-conditions	Coding activity finished. Availability of a static analysis tool.
Report format	Tool dependant, but tabular and graphical results should both be available. Table with the names of the classes, the criticality category of the class and the actually measured value.
Other remarks	A parameterized class is also called a generic class. Parameterized classes should be subject of extra review activities to detect possible problems due to parameterization

A.4.2.3 Parametric polymorphic factor

Main Characteristic	Maintainability
Sub Characteristic	Analyzability
Metric name	Parametric polymorphism factor (Numerator only)
Goal	To assess the degree of complexity induced by (parameterized) polymorphism by providing the percentage of the classes that are parameterized.
Owner / Producer	Owner: development leader Producer: development team
Target audience	SW PA Manager, development leader, V&V leader
Evaluation method	Static code analysis with the support of automatic tools.
Formula	PPF = Parameterized classes/All classes The numerator of the source code metric "Parametric polymorphism factor" is the total number of parameterized classes (also called generic classes or template classes)
Interpretation of measured value	The larger the number of parameterized classes the more complex is the software
Life cycle phase	Collected during design and implementation engineering, SW validation and verification processes. Provided at CDR, and updated afterwards as required.
Applicability	- MANDATORY for criticality categories A-B-C - RECOMMENDED for criticality category D
Pre-conditions	Coding activity finished. Availability of a static analysis tool.

Report format	Tool dependant, but tabular and graphical results should both be available. Table with the names of the classes, the criticality category of the class and the actually measured value.
Other remarks	A parameterized class is also called a generic class. Parameterized classes should be subject of extra review activities to detect possible problems due to parameterization

A.4.2.4 Coupling between objects

Main Characteristic	Maintainability
Sub Characteristic	Modularity
Metric name	Coupling between objects (CBO)
Goal	To measure the number of other classes to which a class is coupled.
Owner / Producer	Owner: development leader Producer: development team
Target audience	SW PA Manager, development leader, V&V leader
Evaluation method	Static code analysis with the support of automatic tools.
Formula	No Formula. Just by counting the number of distinct non-inheritance related class hierarchies on which a class depends.
Interpretation of measured value	CBO<=4 The larger the number of couples, the higher the sensitivity to changes in other parts of the design and therefore maintenance is more difficult
Life cycle phase	Collected during design and implementation engineering, SW validation and verification processes. Provided at CDR, and updated afterwards as required.
Applicability	- MANDATORY for criticality categories A-B-C - RECOMMENDED for criticality category D
Pre-conditions	Coding activity finished. Availability of a static analysis tool.
Report format	Tool dependant, but tabular and graphical results should both be available. Table with the names of the classes, the criticality category of the class and the actually measured value.
Other remarks	Excessive coupling is detrimental to modular design and prevents reuse. Strong coupling complicates a system since a class is harder to understand, change or correct by itself if it is interrelated with other classes. Complexity can be reduced by designing systems with the weakest possible coupling between classes.

A.4.2.5 Lack of cohesion of methods

Main Characteristic	Maintainability
Sub Characteristic	Modularity
Metric name	Lack of cohesion of methods (LCOM)
Goal	To measure the dissimilarity of methods in a class by instance variable or attributes.
Owner / Producer	Owner: development leader Producer: development team
Target audience	SW PA Manager, development leader, V&V leader
Evaluation method	Static code analysis with the support of automatic tools.
Formula	Henderson-Sellers LCOM* Consider a set of m methods, M_1 , M_2 ,... , M_m; the methods access a data attributes, A_1 , A_2 ,... , A_a; let $m(A_k)$ = number of methods that access data A_k. Then $\mathrm{LCOM^*} = \frac{\left(\frac{1}{a}\sum_{j=1}^{a} m(A_j)\right) - m}{1-m}$ Please note: 0 <= LCOM* <=m / (m-1), since the term in brackets is greater or equal zero and smaller or equal m.
Interpretation of measured value	LMOC >= 1.5 x m (m-1) High cohesion indicates good class subdivision. Lack of cohesion or low cohesion increases complexity, thereby increasing the likelihood of errors during the development process. High cohesion implies simplicity and high reusability. High cohesion indicates good class subdivision. Lack of cohesion or low cohesion increases complexity, thereby increasing the likelihood of errors during the development process.
Life cycle phase	Collected during design and implementation engineering, SW validation and verification processes. Provided at CDR, and updated afterwards as required.
Applicability	- MANDATORY for criticality categories A-B-C - RECOMMENDED for criticality category D
Pre-conditions	Coding activity finished. Availability of a static analysis tool.
Report format	Tool dependant, but tabular and graphical results should both be available. Table with the names of the classes, the criticality category of the class and the actually measured value.
Other remarks	Classes with low cohesion could probably be subdivided into two or more subclasses with increased cohesion. For example, an implementation can be the number of times the attributes have been used in each method of the class.