Block #2 – Software PA Organizational Aspects→ SW RAMS

Software PA Organizational Aspects / SW RAMS

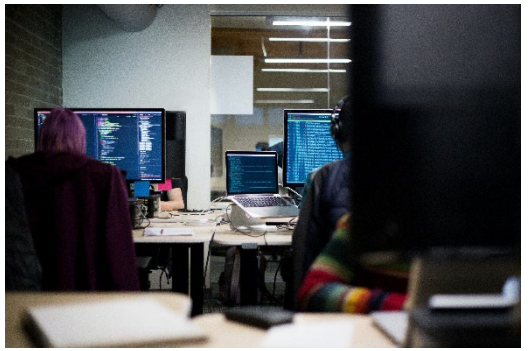
- **Introduction**
  - Why/how SW PA
  - Customer Supplier
  - SW PA in a Space/Ground Segment Project
- **SW PA Organization**
  - Training/Planning/Reporting
  - Supplier Requirements and Monitoring
- **SW Dependability and Safety**
  - Reliability/Availability/Maintainability/Safety
  - Software RAMS overview
- **Software Criticality Classification**
  - Function Criticality Classification
  - Software Criticality Categories (exercises)/HSIA
- **Tailoring of SW PA requirements**

Why SW PA?

Project Manager

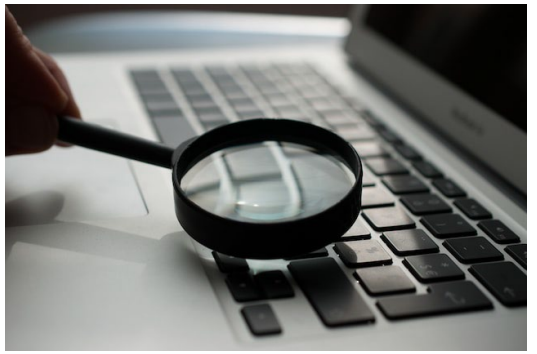
«I want the SW "ready" in time and within budget»

Software Engineer



«I want to see my SW "work"»

Software PA



«I want to see the SW:

- Perform correctly in all foreseen scenarios
- Perform correctly on all foreseen platforms
- Be reliable
- Be robust
- Be maintainable
- Fulfil quality requirements
- … »

Product Assurance

*Discipline devoted to the study, planning and implementation of activities intended to **assure** that the design, controls, methods and techniques in a project result in a satisfactory degree of **quality** in a **product** [ECSS-S-ST-00-01]*

How SW PA?

- Apply requirements meant to ensure the quality of processes and products
- Those requirements are defined in Standards
- ESA applies ECSS ⇨ **ECSS-Q-ST-80**

- Standards' requirements are to be tailored based on criteria related to the specific project
- ECSS-Q-ST-80 includes a pre-tailoring based on software criticality (see later)

What is NOT SW PA

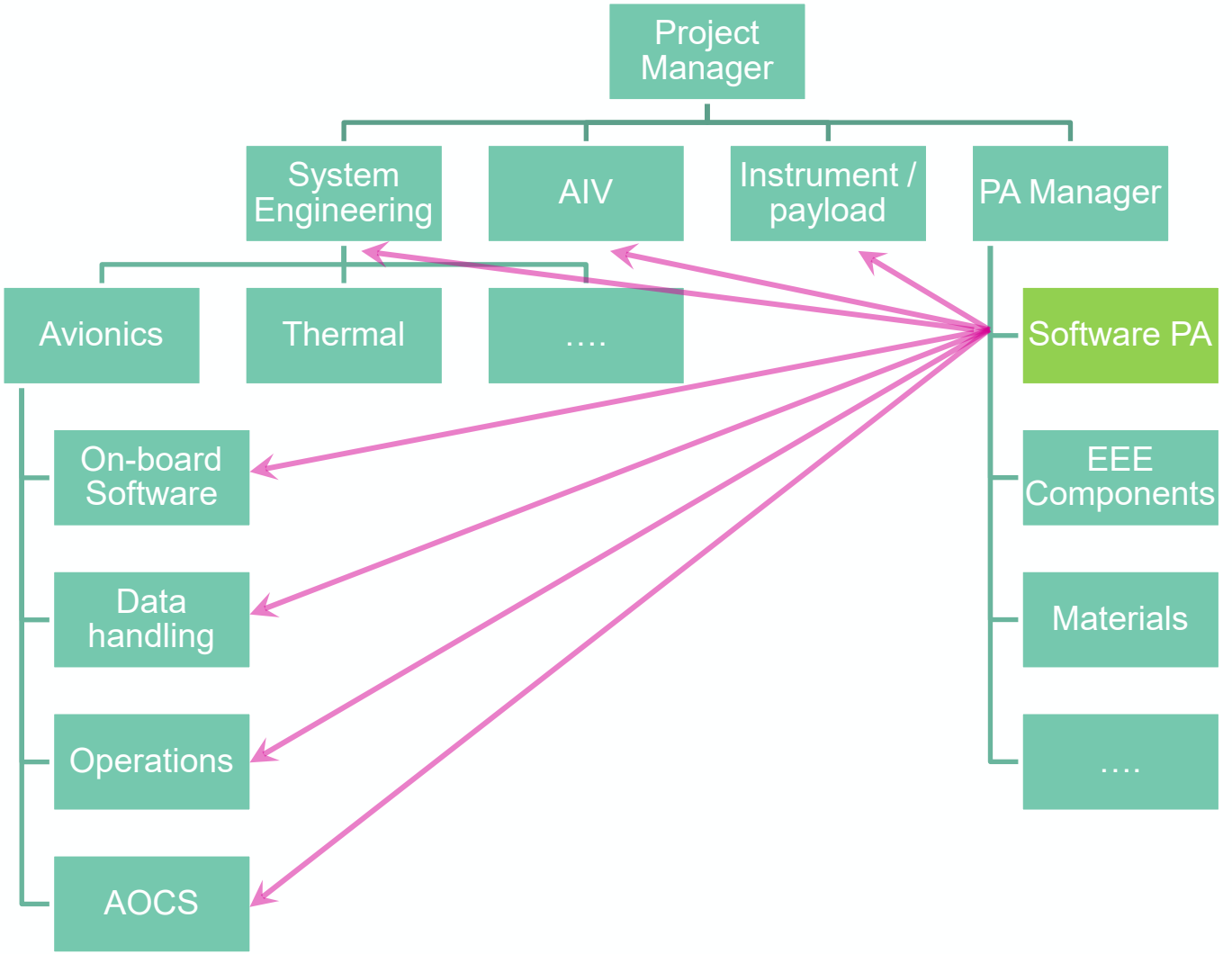
- Verification/Validation
- Testing
- Configuration Management
  (ECSS M40 → SCF Annex E)
- Risk Management (ECSS M80)

Customer and Supplier

- Customer-supplier relationship, typically applied recursively (customer-supplier chain)
  - Intermediate chain levels: often both customer and supplier
- SW PA at customer level
  - Ensures suitability of procurement documentation
  - Defines software product assurance requirements
  - Monitors the suppliers' conformance to SW PA requirements

- SW PA at supplier level
  - Ensures correct implementation of software product assurance requirements
  - Defines a software product assurance programme
  - Reports to customer about implementation software product assurance programme

SW PA in a Space Segment Project



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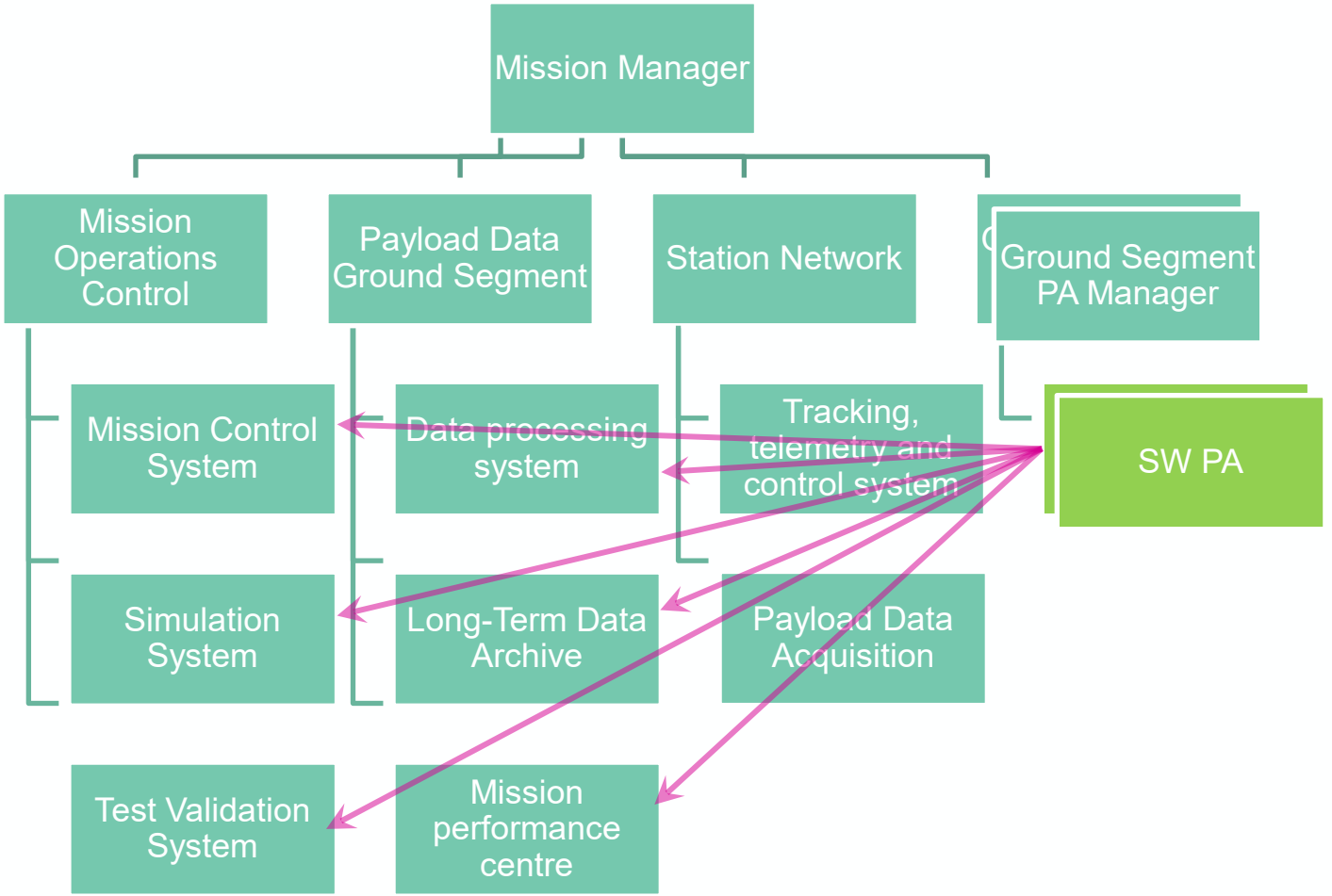
SW PA in a Ground Segment Project



[simplified]

SW PA Organization

- Software suppliers are required to:
- Define an organizational structure for software development
  - Not only PA: all personnel whose work affects quality
- Allocate and make available resources for the SW PA tasks
- Identify personnel in charge of SW PA tasks
  - Software Product Assurance Manager (or Engineer)
- Ensure authority and independence of SW PA in charge
- Grant unimpeded access to higher management

Training

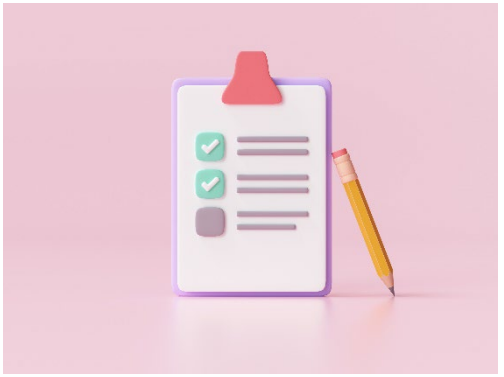
- Ensure that the right composition and categories of appropriately trained personnel are available
- Determine training subjects based on the specific tools, techniques, methodologies and computer resources to be used

- No Specific university degrees in Software Product Assurance around (SW Engineering)
- Build up SW PA skills through training, experience in SW development and PA in general

SW PA Planning

- Develop a Software Product Assurance Plan in response to applicable software product assurance requirements (ECSS Q80/ *possible PARD for suppliers SW requirements)*
  - May be part of the overall project PA plan
  - Not necessarily a tome: only what is realistically feasible

- Ensure Plan is up-to-date at each milestone



  - Include a compliance matrix vs. the applicable software product assurance requirements
  - Include references to the project documentation that will contain the output of the implemented requirements

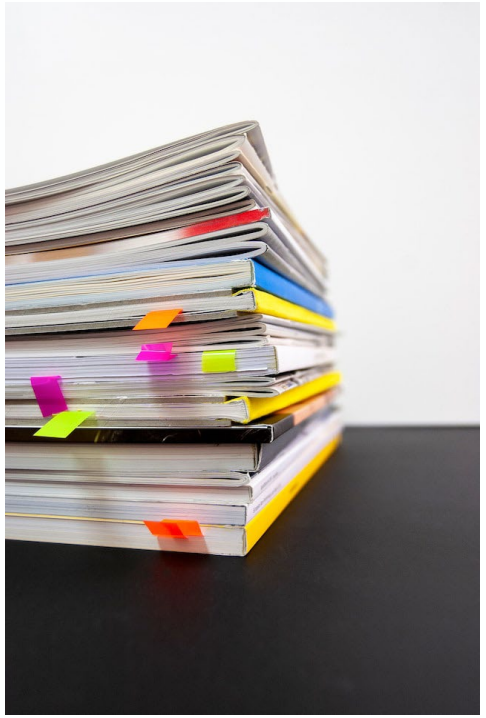
SW PA Reporting

- Regular software product assurance reporting to be provided as part of the overall project reporting
- Specific reporting to be provided at milestone reviews

- Main reporting topics
  - Assessment of product and process quality
  - Verifications undertaken
  - Problems detected and resolved

Supplier Requirements and Monitoring

- PA should be involved in the selection of lower-level suppliers
- When selecting lower-level suppliers that claim (massive) software reuse, a preliminary software reuse file (see later) should be required as part of the proposal



- Software product assurance requirements shall be established for lower-level suppliers
  - To be approved by the customer
- Lower-level suppliers shall be monitored
  - Approve SW PA plan
  - Verify definition and implementation of software development processes, in accordance with SW PA requirements, and quality of products

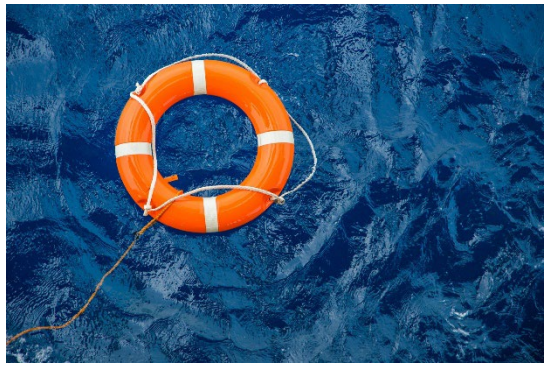
SW Dependability and Safety

- Software RAMS
  - Reliability
  - Availability
  - Maintainability
  - Safety

} Dependability

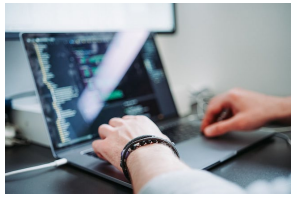
Software RAMS activities start at system level and continue at software level, with mutual feedback

- Main objectives
  - Classify software based on criticality
  - Define and implement measures to handle critical software (including pre-tailoring)



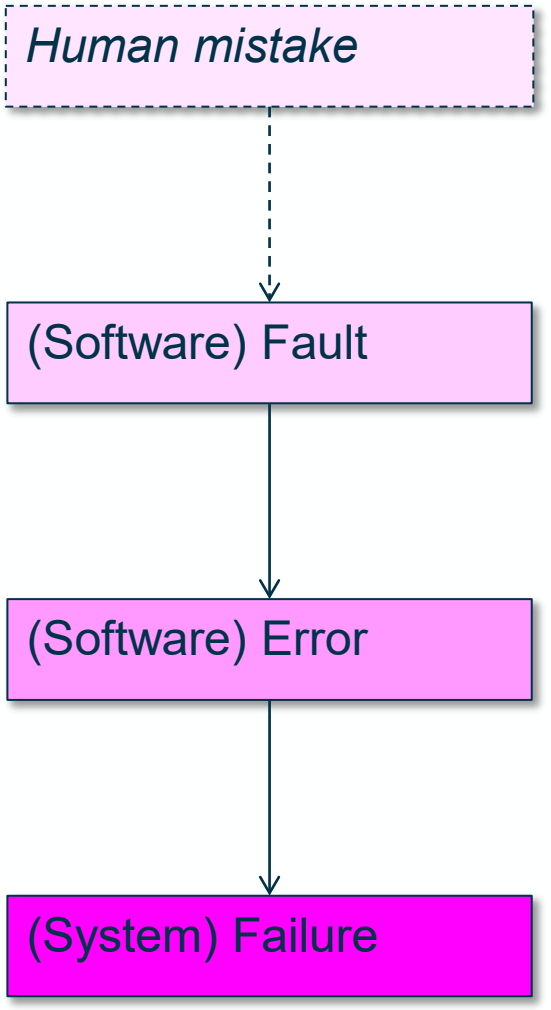
ECSS-Q-HB-80-03
Software Dependability and Safety

Software failures and faults



```
if(1)
{
   x++;
}
```

```
try{…}
catch(error){
…}
```



- Software is a purely intellectual artefact
  - Behaves as programmed
- Do software failures exist?
- Software faults, hence software-caused failures, are systematic
  - No hardware-like wear-out
- Software-caused failures occur randomly
  - Under specific conditions
  - Difficult to predict (much like hardware)

Software Reliability

- Property of being "free from faults"
- Achieved through a set of activities at system and at software level
- Software reliability requirements are derived from system ones
- Compliance with software quantitative requirements can hardly be demonstrated
  - Software reliability models exist **but**
  - Based on assumptions that have proven to be unjustified for most of bespoke software

Software Availability & Maintainability

- Maintainability: capability of the software to be retained or restored to a state in which it can perform a required function, when maintenance is performed
- Especially important for SW with long lifetime

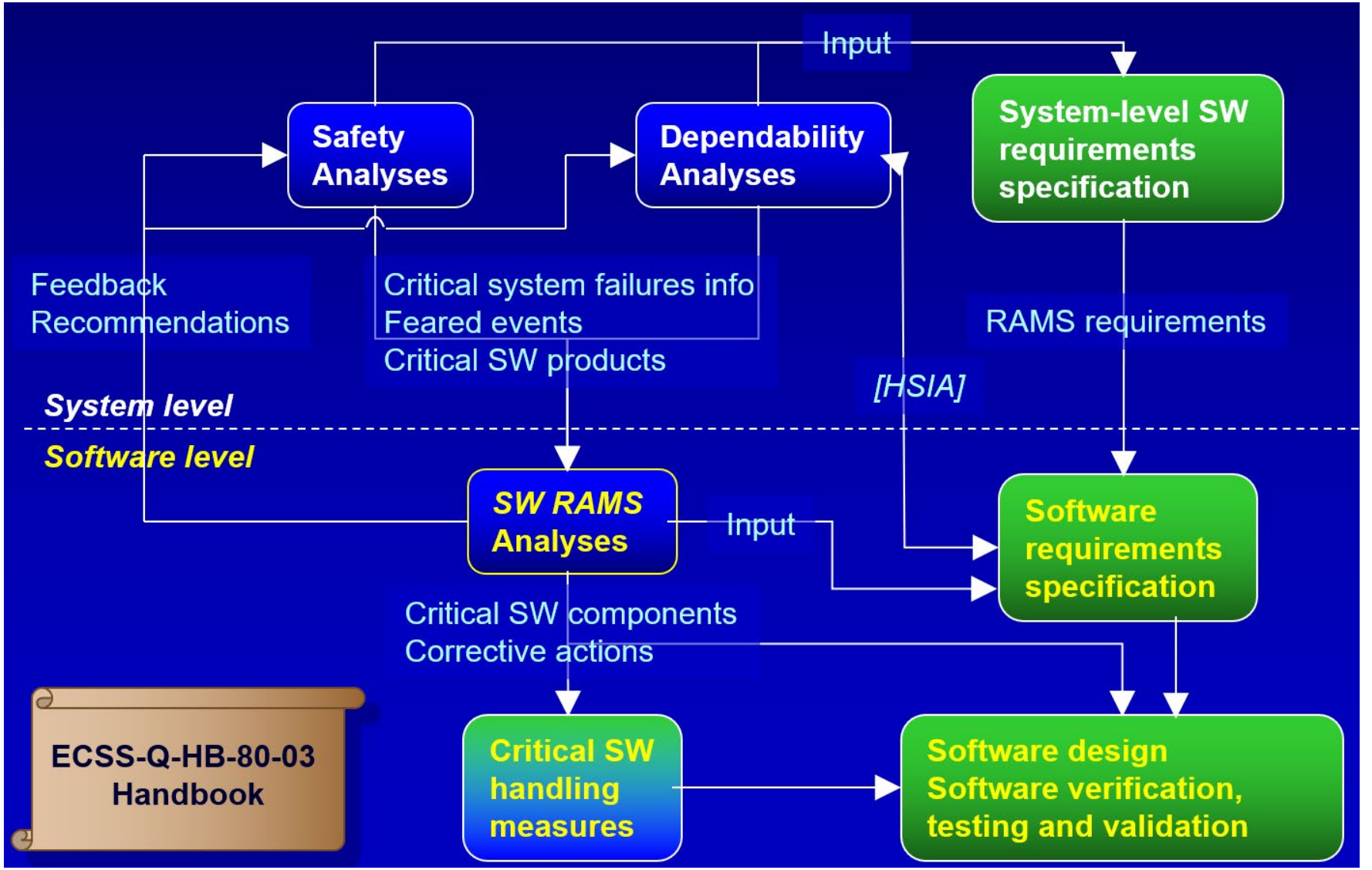
- Availability: capability of the software to perform its function at a given instant or for a time interval
  - It is a function of reliability and maintainability

Software Safety

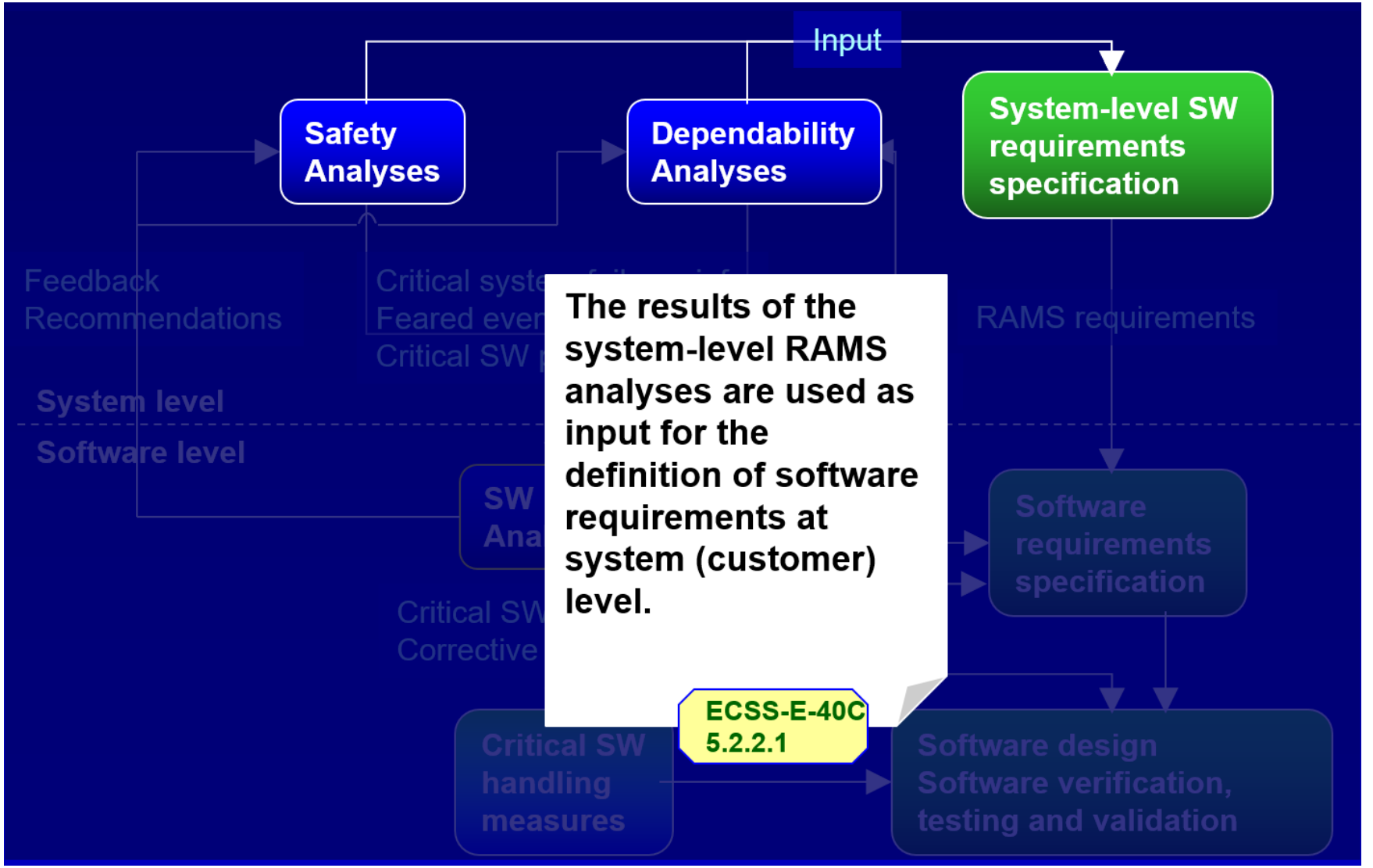
- Safety is a system property
  - Software in itself cannot cause or prevent harm to human beings, system loss or damage to environment
- Safety and reliability are different concepts
  - A system can be reliable but not safe, and vice-versa
- Software safety is the contribution of software to the system safety

- Compliance of software with numerical safety targets cannot be analytically demonstrated
- Approach: design for **minimum risk**

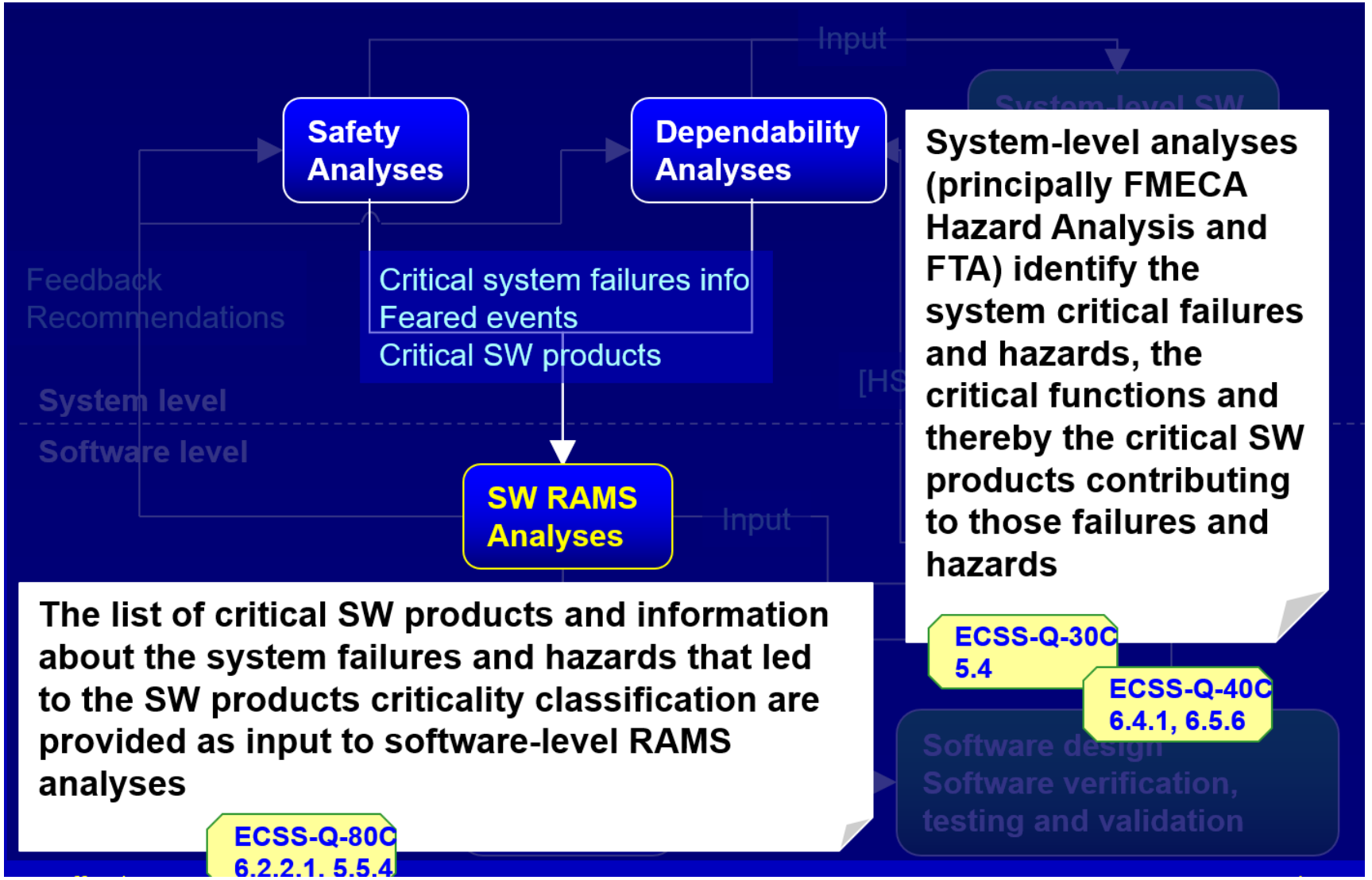
Software RAMS overview (I)



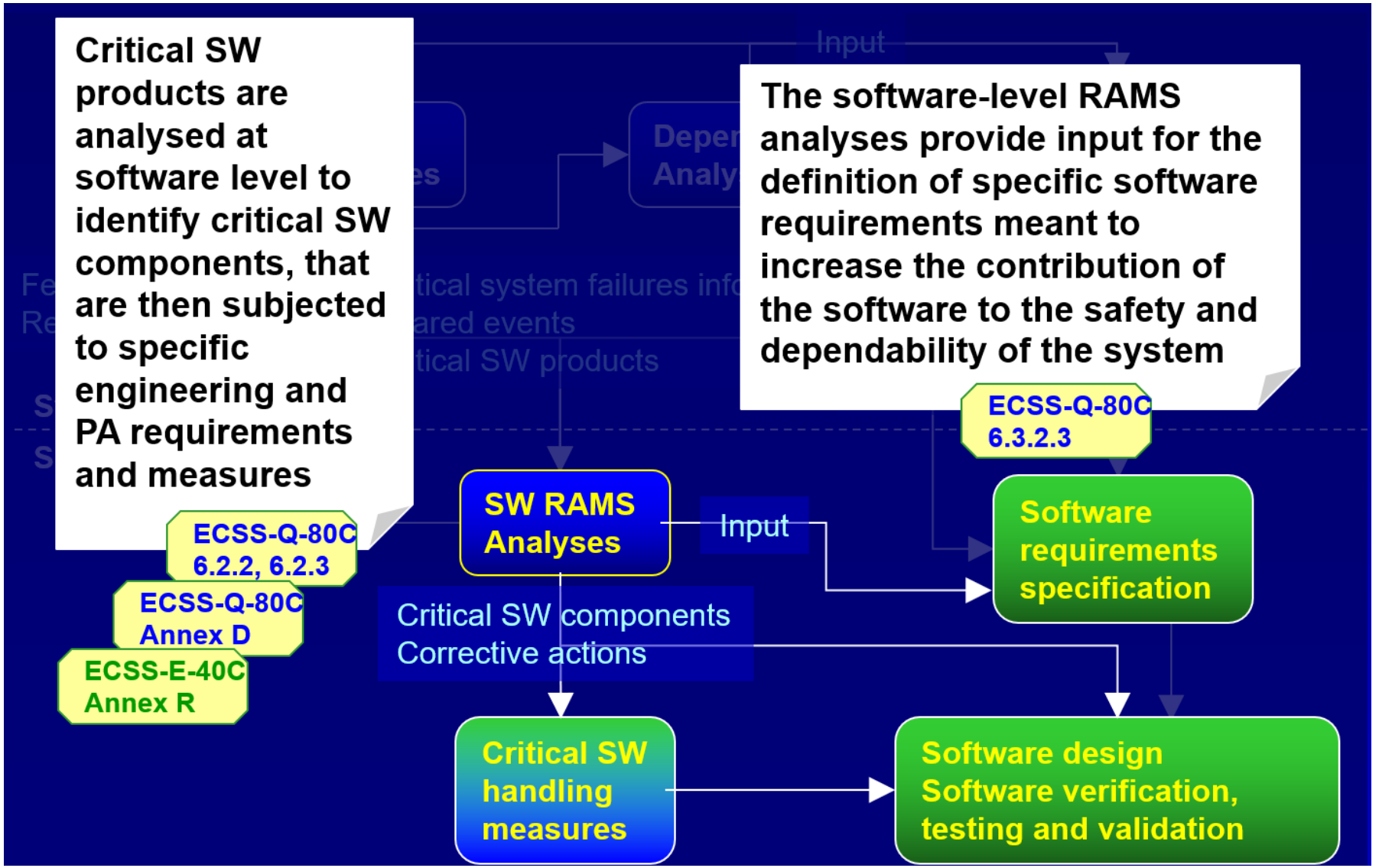
Software RAMS overview (II)



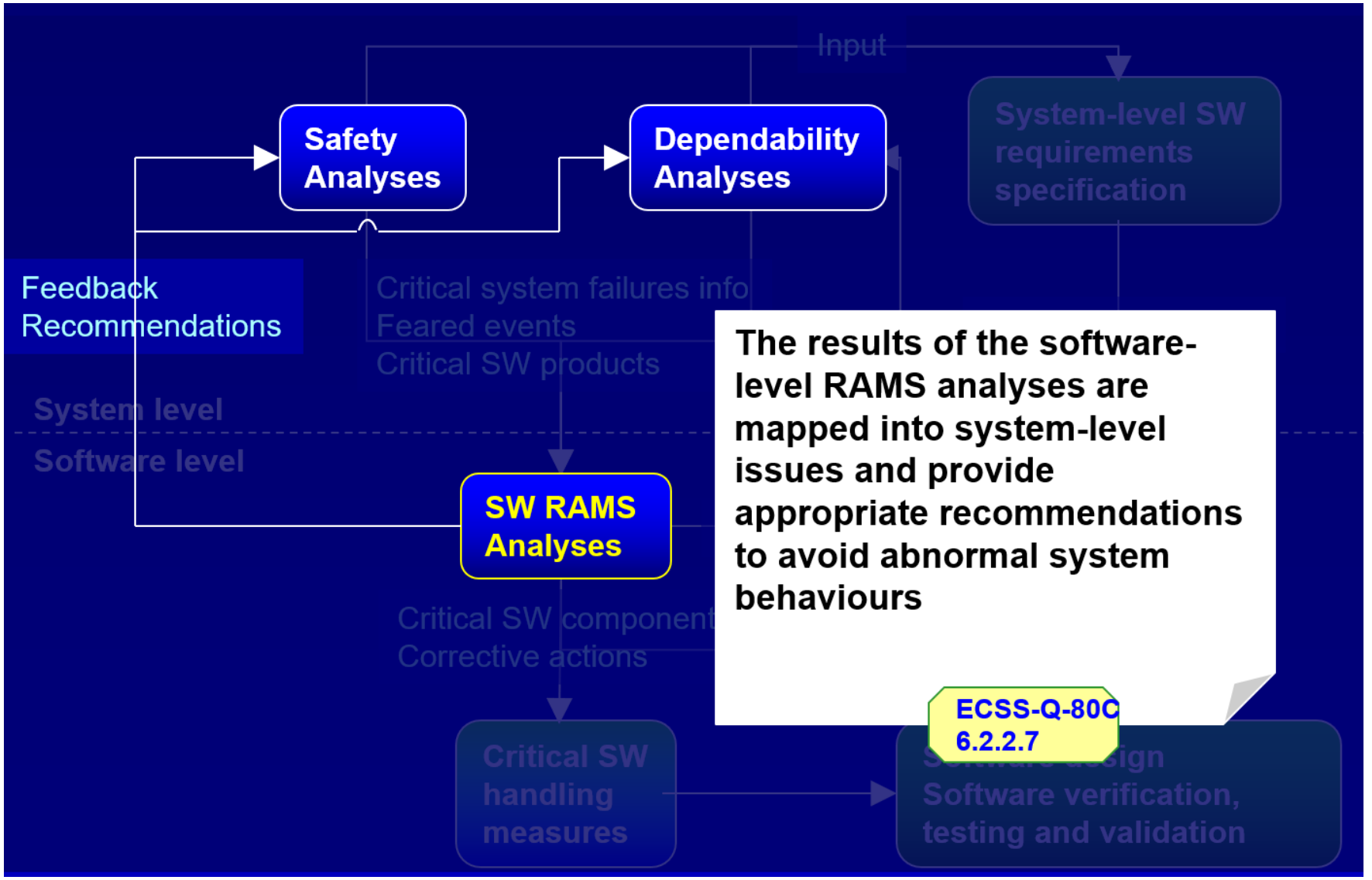
Software RAMS overview (III)



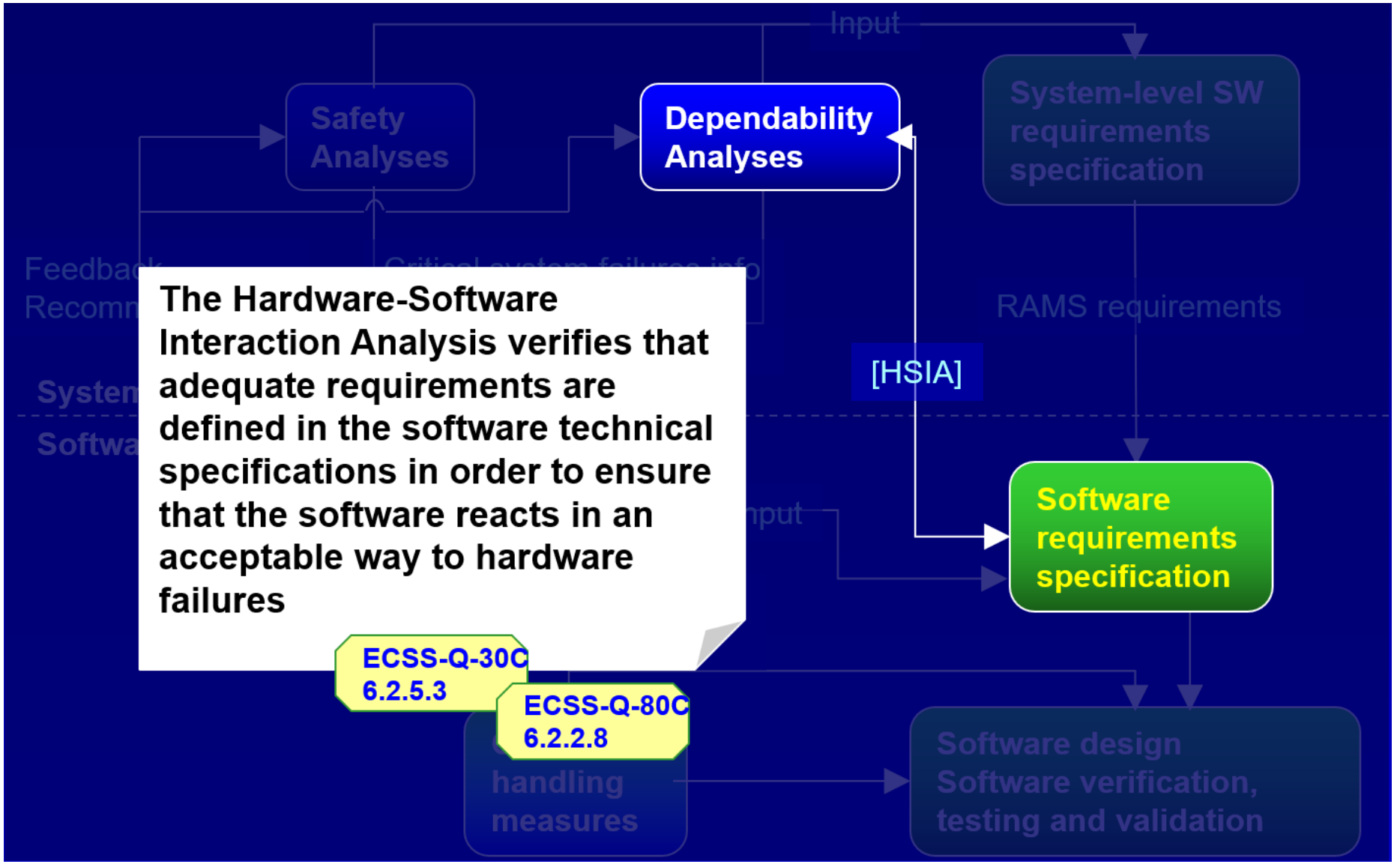
Software RAMS overview (IV)



Software RAMS overview (V)



Software RAMS overview (VI)



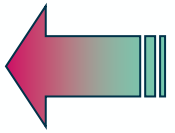
Software Criticality Classification

Criticality Classification

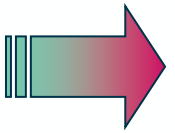
Severity Consequence classification of failures/hazardous events

Criticality classification of system functions

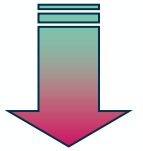
Criticality classification of hardware and operations



- At system level:
  - Dependability analyses (e.g. FME(C)A, FTA)
  - Safety analyses (e.g. Hazard Analysis)



Consideration of compensating provisions



Criticality classification of **software products**

SW Dependability and Safety

Severity	LEVEL	Effect as per DEPENDABILITY (ECSS-Q-30)	Effect as per SAFETY (ECSS-Q-40)
CATASTROPHIC	1	Failure propagation (Only for lower than system level analysis) (refer to requirement 5.3.2.c)	• LOSS OF LIFE, LIFE-THREATENING OR PERMANENTLY DISABLING INJURY OR OCCUPATIONAL ILLNESS. • LOSS OF AN INTERFACING MANNED FLIGHT SYSTEM • SEVERE DETRIMENTAL ENVIRONMENTAL EFFECTS. • LOSS OF LAUNCH SITE FACILITIES. • LOSS OF SYSTEM
CRITICAL	2	COMPLETE LOSS OF MISSION	• TEMPORARILY DISABLING BUT NOT LIFE-THREATENING INJURY, OR TEMPORARY OCCUPATIONAL ILLNESS . • MAJOR DETRIMENTAL ENVIRONMENTAL EFFECTS. • MAJOR DAMAGE TO PUBLIC OR PRIVATE PROPERTIES. • MAJOR DAMAGE TO INTERFACING FLIGHT SYSTEMS, • MAJOR DAMAGE TO GROUND FACILITIES.
MAJOR	3	MAJOR MISSION DEGRADATION	
MINOR OR NEGLIGIBLE	4	MINOR MISSION DEGRADATION OR ANY OTHER EFFECT	

Failure/hazard consequences severity categories

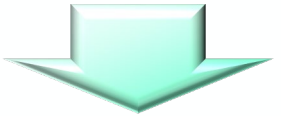
Function Criticality Classification

- Function criticality is directly linked to the severity of failure/hazard consequences, without consideration of compensating provisions

SEVERITY	*FUNCTION CRITICALITY*	*CRITERIA TO ASSIGN CRITICALITY CATEGORIES TO FUNCTIONS*
CATASTROPHIC (LEVEL 1)	I	A FUNCTION THAT IF NOT OR INCORRECTLY PERFORMED, OR WHOSE ANOMALOUS BEHAVIOUR CAN CAUSE ONE OR MORE FEARED EVENTS RESULTING IN CATASTROPHIC CONSEQUENCES
CRITICAL (LEVEL 2)	II	A FUNCTION THAT IF NOT OR INCORRECTLY PERFORMED, OR WHOSE ANOMALOUS BEHAVIOUR CAN CAUSE ONE OR MORE FEARED EVENTS RESULTING IN CRITICAL CONSEQUENCES
…	…	…

Hardware, Operation and SW Products Criticality

- Criticality of hardware and operations is determined in accordance with the highest criticality of functions implemented
- Criticality of software is assigned, considering the overall system design,



- In particular whether compensating provisions exist that can prevent or mitigate failure consequences (e.g. inhibits, monitors, back-ups, operational procedures)
- Compensating provisions allow to "*downgrade*" the software criticality (of 1 category only)

Software Criticality Categories (I)

FUNCTION CRITICALITY	*CRITICALITY CATEGORY TO BE ASSIGNED TO A SOFTWARE PRODUCT*
I	CRITICALITY CATEGORY **A** IF THE SOFTWARE PRODUCT IS THE SOLE MEANS TO IMPLEMENT THE FUNCTION
	CRITICALITY CATEGORY **B** IF, IN ADDITION, AT LEAST ONE OF THE FOLLOWING COMPENSATING PROVISIONS IS AVAILABLE, MEETING THE REQUIREMENTS DEFINED IN CLAUSE 5.4.2: - A HARDWARE IMPLEMENTATION - A SOFTWARE IMPLEMENTATION; THIS SOFTWARE IMPLEMENTATION SHALL BE CLASSIFIED AS CRITICALITY **A** - AN OPERATIONAL PROCEDURE
II	CRITICALITY CATEGORY **B** IF THE SOFTWARE PRODUCT IS THE SOLE MEANS TO IMPLEMENT THE FUNCTION
	CRITICALITY CATEGORY **C** IF, IN ADDITION, AT LEAST ONE OF THE FOLLOWING COMPENSATING PROVISIONS IS AVAILABLE, MEETING THE REQUIREMENTS DEFINED IN CLAUSE 5.4.2: - A HARDWARE IMPLEMENTATION - **A SOFTWARE IMPLEMENTATION; THIS SOFTWARE IMPLEMENTATION SHALL BE CLASSIFIED AS CRITICALITY B** - AN OPERATIONAL PROCEDURE

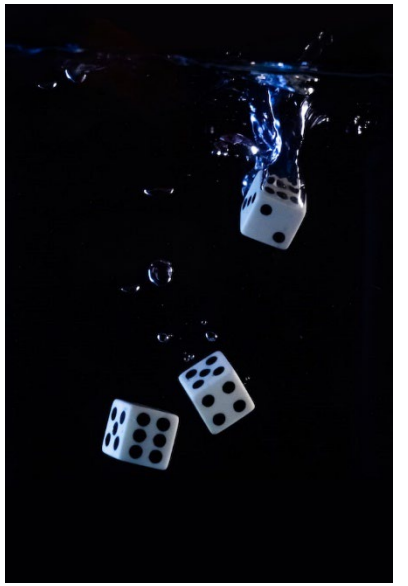
Software Criticality Categories (II)

FUNCTION CRITICALITY	***CRITICALITY CATEGORY TO BE ASSIGNED TO A SOFTWARE PRODUCT***
III	CRITICALITY CATEGORY **C** IF THE SOFTWARE PRODUCT IS THE SOLE MEANS TO IMPLEMENT THE FUNCTION
	CRITICALITY CATEGORY **D** IF, IN ADDITION, AT LEAST ONE OF THE FOLLOWING COMPENSATING PROVISIONS IS AVAILABLE, MEETING THE REQUIREMENTS DEFINED IN CLAUSE 5.4.2: - A HARDWARE IMPLEMENTATION - A SOFTWARE IMPLEMENTATION; THIS SOFTWARE IMPLEMENTATION SHALL BE CLASSIFIED AS CRITICALITY **C** - AN OPERATIONAL PROCEDURE
IV	CRITICALITY CATEGORY **D**

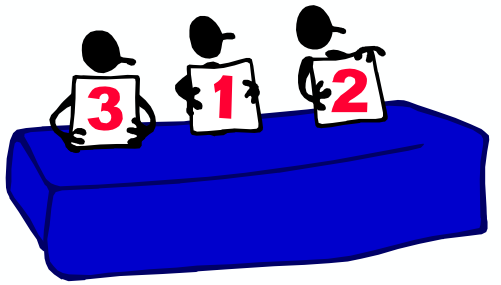
NOTE: IT SHOULD BE NOTED THAT A TOO HIGH LEVEL/INCOMPLETE FUNCTIONAL DECOMPOSITION, POORLY ACCOUNTING FOR SAFETY AND DEPENDABILITY ASPECTS, COULD LEAD TO A UNNECESSARILY CONSERVATIVE SOFTWARE CATEGORY CLASSIFICATION.

Compensating Provisions

- Conditions are established for acceptable compensating provisions in the SW criticality assignment
  - Probabilistic assessment cannot be used as a criterion for SW criticality classification
  - Effectiveness of compensating provisions (for the purpose of "downgrading") must be demonstrated in all conditions
  - There must be sufficient time to intervene in all situations
  - In case the compensating **provisions contain software, this software shall be classified at the criticality** category corresponding to the highest severity of the failure consequences that they prevent or mitigate (consider the case of mixed criticality segregation)



SW Dependability and Safety



- The supplier is expected to perform a software dependability and safety analysis to determine the criticality category of software *components*
- Analysis to be performed at technical specification and design level, e.g.:
  - Software Failure Modes and Effects Analysis (SFMEA)
  - Software Fault Tree Analysis (SFTA)
  - Software Common Cause Analysis (SCCA)
- The software criticality classification must be confirmed at each milestone

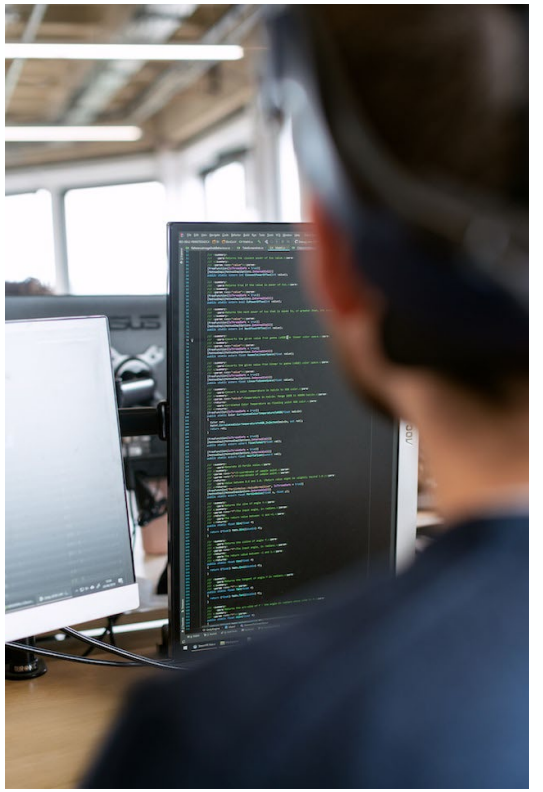
SW Dependability and Safety

- The supplier shall apply engineering measures to reduce the number of critical software components

- Propagation of failures from low-criticality to high-criticality SW components shall be prevented
  - If not possible, all involved components shall be classified at the highest criticality level among them
- Contribution of software to Hardware-Software Interaction Analysis
  - Identify, for each hardware failure included in the HSIA, the requirements that specify the software behaviour in the event of that hardware failure

Handling of Critical Software (I)

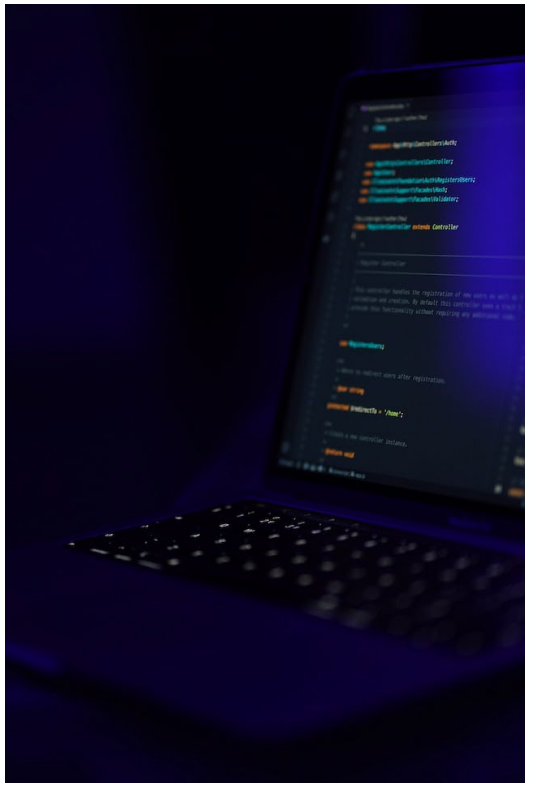
- The supplier shall define, justify and apply measures to assure the dependability and safety of critical software
  - Measure proposed by the supplier and agreed with the customer, e.g.:
  - insertion of features for failure isolation and handling;
  - defensive programming techniques;
  - use of a “safe subset” of programming language;
  - full inspection of source code; etc.



- The correct implementation of the chosen measures shall be verified and reported on

Handling of Critical Software (II)

- Specific requirements for critical software
  - Mandatory regression testing in case of change of hardware or development tools
  - Potential need for additional verification and validation to be analysed in case of change of hardware and environment
  - Remove unreachable code
  - Testing to be (re-)executed on non-instrumented code



Besides the tailoring of engineering and PA requirements

Tailoring of SW PA requirements

- For most projects, making all ECSS-Q-ST-80C requirements applicable is neither sensible nor feasible
  - … and supplier claiming compliance is not credible
- SW PA requirements should always be tailored to the specific project's needs
  - Tailoring is a customer's responsibility!
- Different tailoring drivers may (co-)exist
  - Dependability and safety aspects
  - Software development constraints
  - Product quality objectives and business objectives
- In general, budget should not be the main driver

Pre-tailoring based on criticality

Clause	Description	A	B	C	D
…	…	…	…	…	…
7	**Software product quality assurance**	-	-	-	-
7.1	Product quality objectives and metrication	-	-	-	-
7.1.1	Deriving of requirements	Y	Y	Y	Y
7.1.2	Quantitative definition of quality requirements	Y	Y	Y	Y
7.1.3	Assurance activities for product quality requirements	Y	Y	Y	Y
7.1.4	Product metrics	Y	Y	Y	Bullet 4.(a) not applicable
7.1.5	Basic metrics	Y	Y	Y	Design-relevant and fault density/failure intensity metrics not required
7.1.6	Reporting of metrics	Y	Y	Y	Y
7.1.7	Numerical accuracy	Y	Y	Y	Y
7.1.8	Analysis of software maturity	Y	Y	Y	N
…	…	…	…	…	…

ESA Mission Classification objectives

ESA Mission Classification provides

- ESA programme and project managers a framework to define the appropriate management, engineering and product assurance controls, tailored to the profile of the mission
- A systematic approach for optimising resources in accordance with mission objectives
- A basis for the introduction of novel elements (e.g. Commercial Off The Shelf) and working methods aiming at reducing development time and cost while balancing risk
- ESA & its Member States a new structured framework to manage the programmatic risks

MAIN ASSUMPTIONS

- ESA mission classification encompasses one-off missions (man, non-manned missions), recurring operational spacecraft, IOD/IOV and cubesats. Satellite mega-constellations and launchers are not addressed
- A specific mission class can contain units/payloads with different classes. Namely, mission class is originally defined at project/mission level, but it's possible to conceive different classes for different mission elements on-board the same S/C. Potential differentiation between critical and non-critical equipment to be addressed by the project
- For ECSS Q-Branch, ECSS fully applicable to Class I (and most of Class II)
- More flexibility is given to industry as a function of class of the mission (highest flexibility and associated risk for class V), but also more reliance of ESA on contractor's internal processes, more simplification of the documentation and required reporting, at the cost of the less visibility given to ESA and more delegation of responsibility and of risk is given to industry
- Requirements do not necessarily depend if an equipment is recurrent or not. Heritage will be reflected in equipment category defined during EQSR (Equipment Qualification Status Review)
- Possibility to combine deliverable documents mainly for class IV and V missions
- Security and safety (comprising space debris requirements/policy) are not subject to tailoring
- Additional tailoring (up and down in addition to pre-tailoring) still possible at project level

ESA MISSION CLASSIFICATION TABLE

Class type	I	II	III	IV	V
Mission Criteria and Marking					
Criticality to Agency strategy (Flagship mission, Internationnal cooperation, Impact on ESA strategic goals, and image)	Extremely high Criticality	High Criticality	Medium Criticality	Low Criticality	Educational purposes
Marking					
Mission Objectives (Directorate priority and purpose, e.g in orbit demonstration, educational)	Extremely high Priority	High Priority	Medium Priority	Low Priority	Educational purposes
Marking					
Cost (Cost at Completion, Including Phase E1)	>700 M€	200 - 700M€	50 - 200M€	1- 50M€	< 1M€
Marking					
Mission Lifetime (Nominal mission life duration)	> 10 years	5-10 years	2-5 years	1-2 years	1 year
Marking					
Mission Complexity (Design interfaces unique payloads, New technology development)	High	High to Medium	Medium	Medium to Low	Low
Marking					

I. Critical strategy/safety (e.g. manned missions) (High level of requirements and low risk)

I. Performances should be met whatever it takes

II. Finding the best compromise between risk and cost to deliver the mission

III. Mission is designed according to a hard cost limit (affordability approach)

IV. Almost full delegation to industry (Minimum requirements but increased risk)

ESA MISSION CLASSIFICATION - Marking and Classification

ESA Mission: Vigil

- **Extremely critical to the Agency (Criticality is then Class I)**
- **Mission objectives considered High Priority (Objectives in Class II)**
- **Cost of the mission: 300 to 400 M€ (Class II)**
- **Mission lifetime: 7 years nominal (Lifetime is then Class II)**
- **Mission complexity: medium (Complexity is then Class III)**

1 <= Total <= 1,5 -------- = Class I
1,5 <Total <= 2,5 -------- = Class II
2,5 < Total <= 3,5 -------- = Class III
3,5 < Total <= 4,5 -------- = Class IV
4,5 < Total <= 5 --------- = Class V

Mission Characteristics Criteria & Related Weighting Factors:	Level >>>	I	II	III	IV	V	Input Score (1/2/3/4/5)	Weighted Score
Criticality to Agency Strategy		Extremely High Criticality	High Criticality	Medium Criticality	Low Criticality	Educational Purpose		
WF (10/20/30 %):	30	x					1	0.30
Mission Objectives		Extremely High Priority	High Priority	Medium Priority	Low Priority	Educational Purpose		
WF (10/20/30 %):	20		x				2	0.40
Cost		> 700 M€	200 – 700 M€	50 – 200 M€	< 50 M€	< 1 M€		
WF (10/20/30 %):	10		x				2	0.20
Mission Lifetime		> 10 years	5-10 years	2-5 years	< 2 years	< 1year		
WF (10/20/30 %):	10		x				2	0.20
Mission complexity		High	High to Medium	Medium	Medium to Low	Low		
WF (10/20/30 %):	30			x			3	0.90
Total % (must be 100):	100						Total (*):	2.00
Legenda:				(*)			CLASS:	II

Sub-WG Software
Software product assurance Q-80C Rev1
Software general requirements E-40C

Fully applicable	Modified	Not Applicable

Topics	Class II	Class III	Class IV	Class V
Modified tailoring per software criticality category	ECSS fully applicable	Reduction of criticality level requirements “one level”	Reduction of criticality level requirements “one level”	Starting point to define the tailoring for Class V: •STR-283 – Product Assurance Guidelines for Cubesat Projects (Draft) •Product and Quality Assurance Requirements for In-Orbit demonstration CubeSat Projects. TEC-SY/129/2013/SPD/RW. Iss. 1, Rev. 2. •Tailored ECSS Engineering Standards for In-Orbit Demonstration CubeSat Projects. TEC-SY/128/2013/SPD/RW. Iss. 1, Rev. 3.
	ECSS fully applicable	Major changes allowing electronic access to information in certain cases (avoiding “traditional” documentation). Not constrained by DRDs.	Major changes allowing electronic access to information in certain cases (avoiding “traditional” documentation). Not constrained by DRDs.	
Content of software documentation	ECSS fully applicable	Significant merging of documents	Significant merging of documents	
Software reviews	ECSS fully applicable	Reduction of reviews	Encourage reduction of reviews, and relaxing the level of formality of reviews	
Requirements on software testing	ECSS fully applicable	Reduction in documentation needed for software unit and integration testing	Streamlined approach of software unit and integration testing	
Requirements on reused software	ECSS fully applicable	Reduction in documentation needed for reused software	Streamlined approach for reused software	

Note: Tailoring done in ECSS-E-ST-40C shall be reflected into the project SSRD

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