

Overview of the Second Edition of ISO 26262: Functional Safety— Road Vehicles

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Functional safety is of the utmost importance in the development of safety-critical automotive systems, especially with the introduction of driver assist and automated driving systems. ISO 26262: Functional Safety – Road Vehicles, has been the de facto standard for functional safety in the automotive electronics domain since the release of its first edition in 2011. It is currently available in its second edition, published in December 2018.

In this paper, we present an overview of the standard, which applies to all activities during the safety lifecycle of system development. In the concept phase of ISO 26262, the hazard and risk assessment process focuses on identifying possible hazards caused by malfunctioning behavior of electrical/electronic (E/E) safety-related systems and mitigating them through the identification of safety goals. The design phase includes system, hardware, and software development, with requirements developed from the safety goals. ISO 26262 also prescribes the functional safety management activities to be performed during the safety lifecycle and provides requirements for the supporting processes.

In addition to presenting an overview of the standard, this paper highlights some major changes introduced in the second edition of ISO 26262.

1. Introduction

Safety-critical systems are systems that have the potential to create safety-related issues if they do not operate properly or as designed [Refs. 1 & 2]. These systems are, in general, analyzed using rigorous and systematic safety processes that define all safety activities during the lifecycle development of the system [Ref. 3]. In the automotive domain, ISO 26262: Functional Safety – Road Vehicles [Ref. 4] emerged in 2011 as the go-to standard for functional safety; it was launched as the adaptation of IEC 61508 [Ref. 5] to comply with needs specific to the application sector of electrical/electronic systems within road vehicles.

ISO 26262 applies to all activities during the safety lifecycle of system development. In the concept phase, the hazard and risk assessment process focuses on identifying possible hazards caused by malfunctioning behavior of E/E safety-related systems and mitigating them through the identification of safety goals. The

design phase includes system, hardware and software development, with requirements derived from the safety goals. ISO 26262 also prescribes the functional safety management activities to be performed during the safety lifecycle and provides requirements for the supporting processes.

As is the case with the introduction of any new process, lessons have been learned from the application of the first edition of ISO 26262, and those learnings necessitated the early release of the second edition, which was published in December 2018 [Ref. 6]. The scope of applicability has been extended to include all road vehicles as part of the improvement to the standard. In addition, channels of communication between functional safety and cybersecurity have been identified at both the functional safety management level and product development at the system level. Requirements on trucks, buses, trailers and semi-trailers, as well as their supporting processes, have been introduced in the second edition. A new section, defining motorcycle-specific requirements in the safety lifecycle, has been added. Guidance on semiconductor development has also been described in a new informative part of the standard. Finally, improvements have been made to many of the existing definitions and requirements, along with some restructuring to enhance readability.

This paper is organized as follows: Section 2 describes the basic definitions used in the standard, as well as its scope of applicability. Section 3 introduces the functional safety management, while Section 4 discusses the approach for hazard analysis and risk assessment. Section 5 introduces requirements of product development at the system, hardware and software levels, in addition to a brief summary discussing requirements for production, operation, service and decommissioning. Section 6 summarizes required supporting processes and discusses some safety analyses. Section 7 introduces specific requirements for motorcycles, while Section 8 introduces requirements for trucks, buses, trailers and semi-trailers. Section 9 provides guidance on semiconductor development, while Section 10 provides a general summary.

2. Scope of Applicability and Definitions

ISO 26262 is the adaptation of IEC 61508 [Ref. 5] to comply with needs specific to the application sector of electrical/electronic systems within road vehicles. It

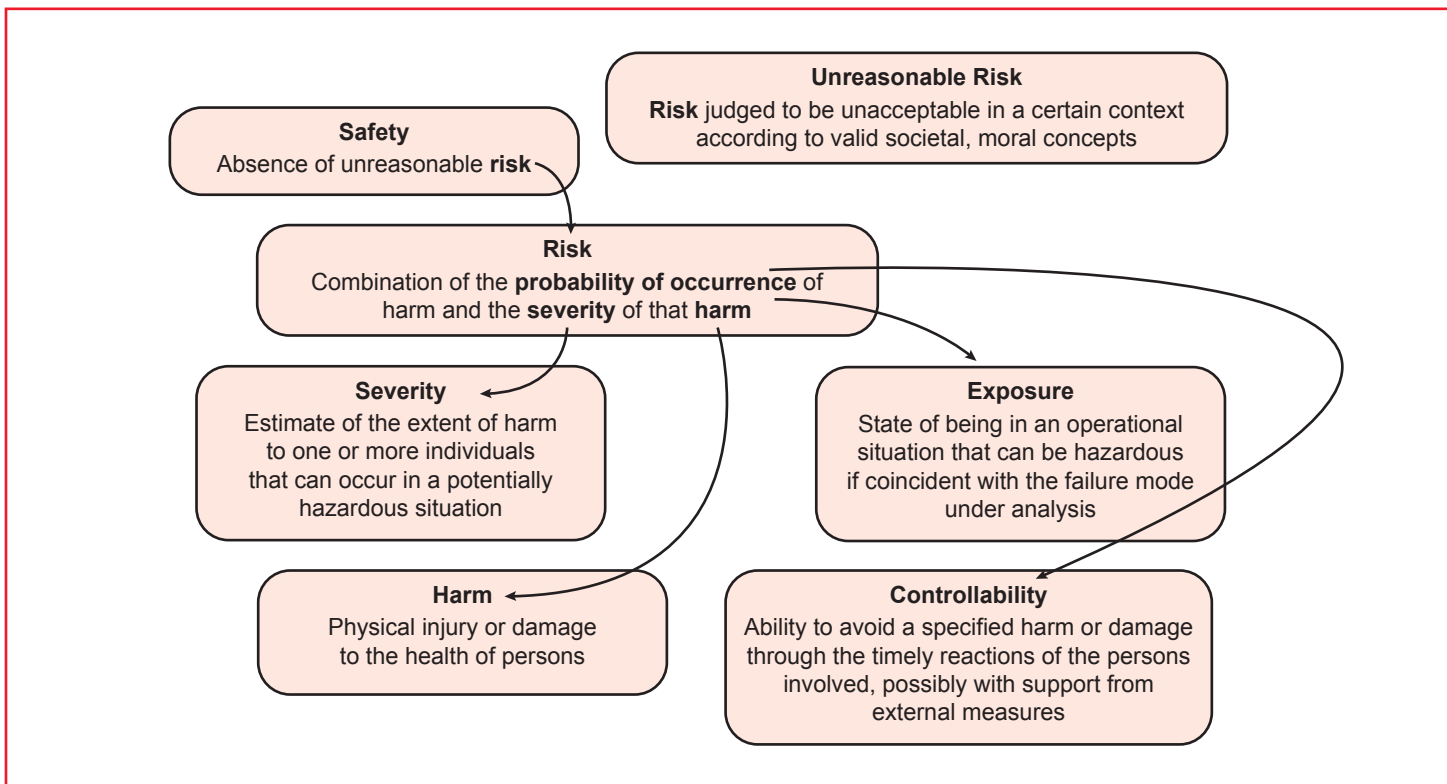


Figure 1 — ISO 26262 Definitions of Safety and Risk.

applies to all activities during the safety lifecycle of system development and its scope has been expanded to include all series production road vehicles. Prior to this modification, the scope of the first edition limited the applicability to vehicles with more than four wheels (carrying passengers or goods) with a maximum vehicle gross mass of up to 3,500 kilograms.

ISO 26262 defines functional safety as the absence of unreasonable risk due to any potential source of harm caused by malfunctioning behavior of electrical and/or electronic systems. A malfunctioning behavior is not limited to failures; it also includes unintended behavior (with respect to design intent).

Figure 1 describes how safety is defined in ISO 26262 as the absence of risk judged to be acceptable given valid societal and moral concepts. Risk itself is computed using three factors: severity, exposure and controllability. It is worth emphasizing here that the concept of “harm” is defined in the context of injury or damage to humans.

Figure 2 provides a classification of ISO 26262-specific terminologies, starting with a system or combination of systems to which the standard applies. The item itself implements a given function at the vehicle level. The system is a set of components, such as a sensor, a controller and an actuator. Components are comprised of hardware parts and software units. The concept of an “element” is introduced, referring to a system, component, a hardware part and a software unit.

Finally, the following are definitions of a few concepts are introduced or emphasized in ISO 26262:

- **Safety Goal** — A top-level safety requirement resulting from the hazard analysis and risk assessment, as described in Section 4
- **Safe State** — The mode of operation, without an unreasonable level of risk, of the item following the occurrence of a failure
- **Safety Mechanism** — The technical solution to detect and mitigate (through avoidance or control) faults and/or failures to maintain intended functionality, or achieve or maintain a safe state
- **Work Product** — Documentation that results from an ISO 26262 requirement(s)
- **Confirmation Review** — Confirmation that a work product provides sufficient and convincing evidence of the achievement of functional safety
- **Safety Case** — Documentation to communicate a clear, comprehensive and defensible argument (supported by evidence compiled in work products) that a system is acceptably safe to operate in a particular context

3. Functional Safety Management

Functional safety management involves planning, coordinating and documenting all activities related to functional safety. In general, it involves the following, as pictured in Figure 3:

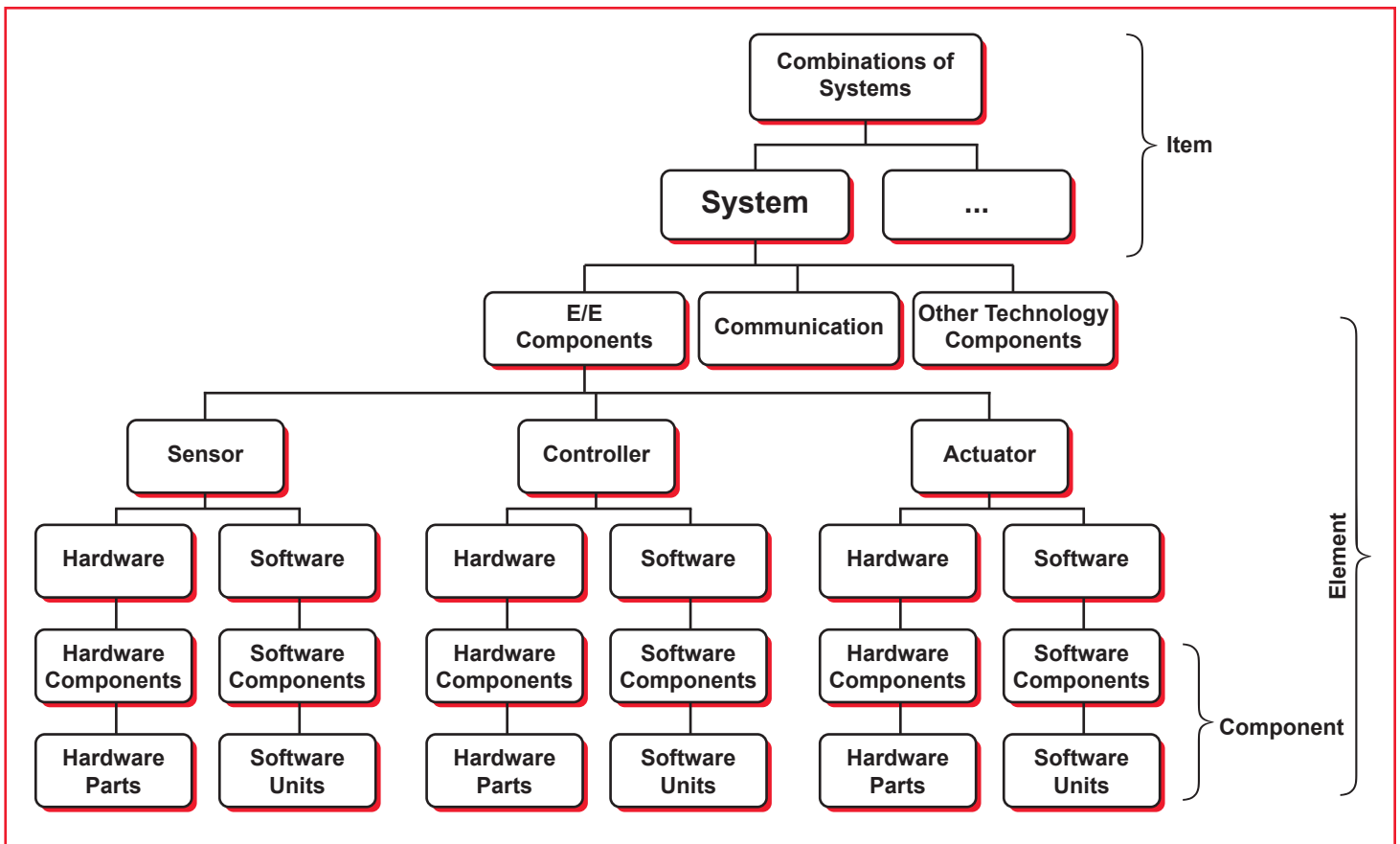


Figure 2 — ISO 26262 Terminologies.

- establishing an internal functional safety process for the company
- establishing a safety organization that oversees the institutionalization of a safety culture within the company, as well as the definition of roles and responsibilities within that organization
- training and qualifying employees to perform safety activities
- institutionalizing functional safety confirmation measures, including reviews, audits and assessments
- managing all corresponding documentation aspects

Part 2 of ISO 26262 discusses implementing a management plan for all phases of the safety lifecycle, including:

- the overall safety management
- the project-dependent safety management
- the safety management for production, operation, service and decommissioning

Overall safety management involves defining requirements for organizations that are responsible for or perform safety activities in the safety lifecycle. A management plan is put forward to incorporate:

- institutionalization of the safety culture
- effective communication channels between functional safety and cybersecurity (a new topic introduced in the Second Edition of ISO 26262)
- organization-specific rules and processes
- processes to resolve safety anomalies
- competence management
- quality management
- project-independent tailoring of the safety lifecycle

Project-dependent safety management involves defining requirements for safety management during the concept and development phases of a project, including roles and responsibilities, as well as performing an impact analysis at the item level in case of a modified/re-used item. A management plan is put forward to incorporate:

- roles and responsibilities in safety management
- impact analyses and tailoring of safety activities
- planning and coordinating of safety activities
- progression of the safety lifecycle
- safety case development
- confirmation measures

It is worth mentioning here that the impact analyses and tailoring of the safety activities have been added to

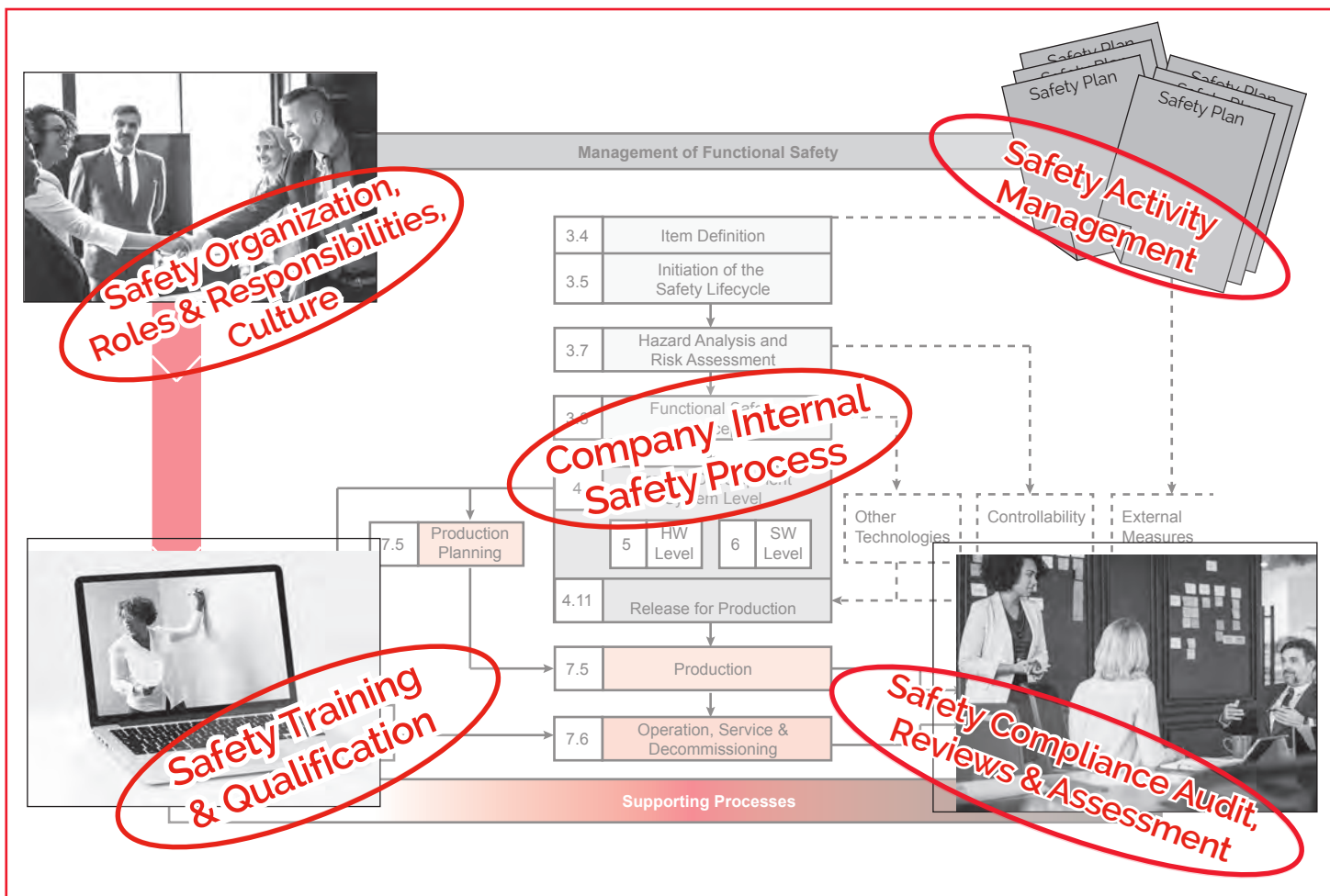


Figure 3 — Management of Functional Safety.

the functional safety management of a given project versus being performed at different phases of development as required by the First Edition of ISO 26262. Moreover, the confirmation reviews (part of the confirmation measures) have been re-defined to provide sufficient and convincing evidence of the achievement of functional safety — an objective-oriented approach compared to the prescriptive definition of meeting requirements in the First Edition of ISO 26262.

Safety management for production, operation, service and decommissioning involves defining responsibilities of persons and organizations in charge of achieving and maintaining functional safety regarding production, operation, service and decommissioning. For instance, requirements are established to appoint persons to execute processes to achieve and maintain the functional safety of the item regarding field monitoring and collection of data.

4. Hazard Analysis and Risk Assessment

In Part 3 of ISO 26262, potential hazards are identified following an analysis of the operational situations of the item. The item may be a vehicle, a vehicle system or a vehicle function. The identified potential hazards are then categorized based on the following factors:

severity, probability of exposure and controllability. Following the categorization results, an automotive safety integrity level, or ASIL, is determined for the potential hazard. The ASIL is also assigned to the safety goal(s) formulated to prevent or mitigate the potential hazard and avoid unreasonable risk. Safety requirements are then derived from these safety goals and inherit the corresponding ASIL. The following provides a brief overview of these activities and the reader is referred to [Ref. 7] for a detailed account:

Situation Analysis and Hazard Identification — The potential hazards are determined given the operating modes of the item in which a malfunctioning behavior may trigger them. These hazards are described and evaluated, and their consequences are identified and documented.

Hazard Classification — The identified potential hazards are classified based on the estimation of severity, probability of exposure and controllability as defined in Section 2. Severity (S) has four classes, ranging from S0 (no injuries) to S3 (fatal injuries). Exposure (E) ranges from an E0 (an extremely unusual situation) to E4 (a highly likely situation). Finally, controllability (C) ranges from C0 (simply controllable) to C3 (uncontrollable).

Table 1 — ASIL Determination (Source ISO 26262 2nd Ed.).

		C1	C2	C3
S1	E1	QM	QM	QM
	E2	QM	QM	QM
	E3	QM	QM	A
	E4	QM	A	B
S2	E1	QM	QM	QM
	E2	QM	QM	A
	E3	QM	A	B
	E4	A	B	C
S3	E1	QM	QM	A
	E2	QM	A	B
	E3	A	B	C
	E4	B	C	D

ASIL Determination — An ASIL is to be determined for each hazardous event using the parameters S, E and C as shown in Table 1. Four ASILs are defined, where ASIL A is the lowest safety integrity level and ASIL D is the highest. In addition to these four ASILs, the class QM (quality management) denotes no requirement in accordance with ISO 26262. Any other requirements such as quality, reliability, and durability, however, must be accounted for.

Safety Goal Formulation — A safety goal is to be determined for each hazardous event evaluated in the hazard analysis. Functional safety requirements needed to avoid an unreasonable risk for each potential hazard are derived from these safety goals which are not expressed in terms of technological solutions, but rather in terms of functional objectives. Functional safety requirements inherit the ASIL of the safety goal from which they are derived.

The ASIL determined for the hazardous event is assigned to the corresponding safety goal. A potential hazard may have more than one safety goal and, if similar safety goals are determined, they can be combined into one safety goal that will be assigned the highest ASIL of the similar goals.

5. Product Requirements at System, Hardware and Software Levels

Product development at the system level starts with developing the technical safety concept. The technical safety concept specifies the technical safety requirements and their allocation to system elements (hardware and software). The technical safety concept defines the system architectural design as well. The development of the technical safety concept is then detailed at both the hardware and software levels. Once the hardware and software development is complete, all elements are integrated and tested. Finally, safety

validation is completed at the vehicle level — that is, evidence is provided that safety goals have been met. This is graphically represented in Figure 4 and detailed in the following:

Technical Safety Concept —

The technical safety concept comprises all technical safety requirements. These requirements are the technical refinement of their corresponding functional safety requirements: They specify safety mechanisms to detect faults, and mitigate or control failures that may lead to the violation of these functional safety requirements and hence, the safety goals. These technical safety requirements inherit the ASIL of the functional safety require-

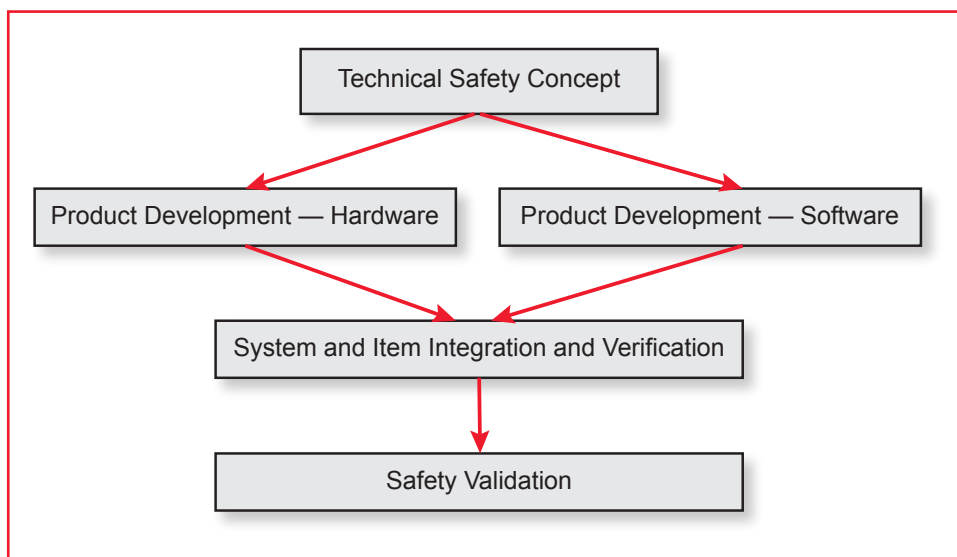


Figure 4 — Product Development at the System Level.

ments they refine. In addition, a system architectural design that implements the technical safety requirements is defined as part of the technical safety concept and is supposed to be suitable to satisfy the safety requirements according to their respective ASIL.

In defining technical safety requirements, some of these requirements may come from a cybersecurity concept as a result of the established channels of communication between functional safety and cybersecurity discussed in the functional safety management summary. Moreover, some technical safety requirements are derived to address safety issues during production, operation, service and decommissioning.

Product Development at the Hardware Level —

At this level, a hardware implementation of the technical safety concept is specified, and safety analyses are performed to find potential faults and their effects on the violation of safety goals. In addition, any required coordination with development at the software level is identified.

The hardware implementation of the technical safety concept involves identification of hardware requirements or, in other words, assignment from technical safety requirements to hardware elements given the system architectural design. The hardware design itself is supposed to be consistent with the system architectural design specification and fulfills the hardware safety requirements while protecting against safety concerns considering the performed safety analyses. The suitability of the hardware architectural design (to detect and control random hardware failures) is assessed using two metrics: single-fault metric and latent-fault metric. Both metrics have target values depending on the ASIL of the requirements being implemented. An alternative approach to assess the suitability of the hardware architectural design (to detect and control random hardware failures) is to evaluate the probability of safety goals violation. The latter can be completed using a global probabilistic approach or by analyzing individual cut sets. In both cases, the assessment is also dependent on the ASIL of the safety goal.

Finally, once all hardware elements are integrated, a verification of the compliance of the hardware design with the hardware safety requirements (given their respective ASILs) is expected.

Product Development at the Software Level — At this level of development software safety, requirements are derived from technical safety requirements, and a software architecture that satisfies all software requirements is developed. In addition, any required coordination with development at the hardware level is identified and/or refined.

Similar to hardware requirements, software safety requirements are derived from the technical safety con-

cept and the system architectural design specification. These requirements inherit the ASIL of their respective technical safety requirements in general. The software architectural design is required to be suitable to satisfy the software safety requirements with their respective ASILs and support the implementation and verification of the software being developed. The latter includes the software unit design, implementation and verification; the software integration and verification; and the testing of the resulting embedded software.

System and Item Integration and Verification —

The integration steps are defined for all levels of integration, including integration of hardware and software of an element, integration of elements resulting in an item, and integration of the item with other systems at the vehicle level. Evidence that the integrated system elements fulfill their safety requirements is also provided. Finally, the proper implementation of safety mechanisms is verified.

Safety Validation — This final step of the system product development provides evidence that the safety goals have been achieved at the vehicle level, and that the developed safety concepts are appropriate for the functional safety of the item. Validation of safety goals is applied to the item integrated at the vehicle level and the validation plan includes test procedures for each safety goal with a pass/fail criterion.

As discussed earlier, some technical safety requirements address safety concerns related to production, operation, service and decommissioning. The objective of these requirements is to ensure that functional safety is achieved throughout the whole lifecycle of the vehicle.

As part of planning for production, operation, service and decommissioning, it is required to develop:

- production processes for safety-related system(s) to be installed in road vehicles
- all necessary information and documentation regarding operation, maintenance and repair, and decommissioning to be used by whoever is interfacing with the safety-related system(s)

In addition to the planning, the production process needs to be analyzed to uncover any process failures and their effects on achieving functional safety. Additionally, the production process must implement and verify the effectiveness of measures to mitigate or control these process failures. Related to the information and documentation for operation, maintenance, repair and decommissioning, a field monitoring process needs to be established to address potential safety-related incidents related to the system(s), with the objective of collecting field data that can be analyzed to detect the presence of functional safety issues and initiate corrective actions for these issues.

Table 2 — ASIL Decomposition Rules

ASIL A	ASIL B	ASIL C	ASIL D
ASIL A(A) + QM(A)	ASIL B(B) + QM(B)	ASIL C(C) + QM(C)	ASIL D(D) + QM(D)
	ASIL A(B) + ASIL A(B)	ASIL B(C) + ASIL A(C)	ASIL C(D) + ASIL A(D)
			ASIL B(D) + ASIL B(D)

6. Supporting Processes and Safety Analyses

Supporting processes are usually labeled “secondary processes” that accompany the core processes and contribute indirectly in delivering a product. For functional safety, ISO 26262 identified a dozen of these processes, each containing a set of consolidated common requirements. Here, we briefly discuss a few of these supporting processes, referring readers to Part 8 of ISO 26262 for a more detailed discussion of all supporting processes.

Interfaces Within Distributed Developments —

This defines the interactions and dependencies between integrators and suppliers for development activities, and describes corresponding allocation responsibilities. In addition, it provides a means to evaluate the supplier’s capability to develop and produce items of comparable complexity and ASIL, according to ISO 26262. The Distributed Interface Agreement (DIA) includes, among many others, requirements on:

- safety managers at the integrator and supplier
- joint tailoring of the safety lifecycle, with identification of activities and processes to be performed by the customer and by the supplier
- information required, work products to be exchanged and persons responsible
- ...

Specification and Management of Safety Requirements —

This process ensures correct specification of safety requirements with respect to attributes and characteristics, and supports consistent management of safety requirements throughout the safety lifecycle. This is achieved by defining requirements on the notations used for the specification of safety requirements, attributes, characteristics and properties of safety requirements, as well as how the safety requirements are managed.

Confidence in the Use of Software Tools — This provides criteria to determine the required level of confidence in a software tool, along with means for the qualification of that software tool. A tool confidence level (TCL) is determined based on analysis, the tool impact

and the tool error detection. Given the TCL, ISO 26262 describes methods to be applied to qualify the software tool, given the ASIL of the safety goal(s).

Qualification of Software Components — This provides evidence for the suitability of the software components for re-use in items developed per the ISO 26262 standard. ISO 26262 requires information to treat a software component as qualified (specification of the software component, evidence that the software component complies with its requirements and is suitable for its intended use, and evidence of an appropriate software development process). It also prescribes requirements for verification of the qualification of the software component.

Evaluation of Hardware Elements — This ensures that the element functional behavior is adequate to meet its allocated safety requirement(s). This type of evaluation is used for commercial off the shelf (COTS) parts not developed per ISO 26262 or considered to be safety related once integrated into an item. In addition, it can be used as an alternative means of compliance with the product development requirements at the hardware level. Different classes are considered, depending on the difficulty of the verification of the safety-related functionality and the role of the hardware element within the safety concept. The evaluation is carried through either testing; testing and analysis; or testing, analysis and argumentation.

Part 9 of ISO 26262 provides an overview of some types of safety analyses. The following briefly describes an ISO 26262 specific method for decomposing requirements.

Requirements Decomposition with Respect to ASIL Tailoring — Known as ASIL decomposition, this is a method to decompose safety requirements into redundant safety requirements (not necessarily identical) to allow ASIL tailoring at the next level of detail. The redundant requirements are allocated to sufficiently independent design elements. It is worth noting here that, even though the development of the design elements to which the redundant requirements are allocated is performed at the decomposed ASIL level, the evaluation of

the hardware metrics and the safety goal violations targets due to random hardware failures remains unchanged by ASIL decomposition. Table 2 provides the rules for ASIL decomposition. These rules can be applied iteratively, as long as traceability is maintained.

7. Motorcycles

Part 12 is a new addition to ISO 26262 Second Edition, and gives an overview of the adaptation of the standard to motorcycles not in the scope of the 1st Edition. All requirements apply to motorcycles; some tailoring, however, is required. Therefore, requirements in Part 12 supersede the corresponding requirements in all other parts.

The major adaptation of requirements in the case of motorcycles applies to the development of the hazard analysis and risk assessment, as well as the determination of the S, E and C parameters. A motorcycle-specific hazard analysis is performed and accounts for:

- the dynamic behavior of motorcycles, which differs greatly from other vehicles
- motorcycle rider dependence to achieve controllability
- operational situations and hazard identification specific to motorcycles

As part of the hazard analysis and risk assessment, a Motorcycle Safety Integrity Level (MSIL) is determined for each hazard from the combination of a motorcycle-specific S, E and C of the hazardous event. The MSIL is later mapped to the ASIL, as depicted in Table 3 and safety goals are assigned to the mapped ASIL. From there onwards confirmation reviews, vehicle integration and testing, and safety validation are performed, given the ASIL.

8. Trucks, Buses, Trailers and Semi-trailers

Truck, buses, trailers and semi-trailers (T&B for short) have been added to the scope of the standard in its Second Edition version. Similar to motorcycles, requirements of Parts 2 through 9 apply to T&B, and any specific modification or new requirements for T&B are listed within the parts of the standard wherever they apply. Additional requirements are listed under:

Table 3 — MSIL to ASIL Mapping

MSIL	ASIL
QM	QM
A	QM
B	A
C	B
D	C

- functional safety management–supporting processes
- hazard analysis and risk assessment
- system-level validation environment
- production, operation, service and decommissioning

Before discussing T&B-specific requirements, it is worth noting here that in the context of T&B, a “body builder” is an organization that adds its own equipment to a base vehicle, such as machine, body or cargo carrier. Consequently, the body builder becomes the integrator in the case of a T&B, while the role of the original equipment manufacturer of the base vehicle is relegated to that of a supplier.

As part of the functional safety management in the case of T&B, a tailoring of safety activities is required when:

- a T&B-related application that is out of scope of ISO 26262 is being interfaced with a base vehicle that has been developed in accordance with ISO 26262, or
- a T&B-related system not developed according to ISO 26262 is to satisfy the required level of functional safety needed for the integration into an item developed in accordance with ISO 26262.

In these specific situations, some development interface agreement (DIA) requirements do not apply.

Interfacing an Application that is Out of Scope of ISO 26262 — An application out of scope of ISO 26262 is supposed to not violate the safety goals of the base vehicle that has been developed in accordance with ISO 26262. In that specific situation, it is required that the integrator is made aware of the modified systems and the permitted safety limits/requirements of the modifications by the manufacturer or supplier. The manufacturer or supplier is, in fact, responsible for communicating safety measures required to be applied by the integrator so that functional safety is maintained.

Integration of Safety-Related Systems not Developed According to ISO 26262 — A development not according to ISO 26262 satisfies the required level of functional safety needed to be integrated into an item developed according to ISO 26262. In that specific situation, the integrator is required to define the criteria to argue that the safety-related system that has been developed to another safety standard meets the required level of functional safety. Consequently, the integrator and the supplier are required to agree on the relevant set of measures to verify that the criteria are met.

Hazard Analysis and Risk Assessment — In the context of T&B, variances of T&B vehicle operation are defined as the use of a T&B vehicle with different dynamic characteristics influenced by cargo or towing during the service life of the vehicle. As a consequence, while performing the hazard analysis and risk assessment, the following variances are to be considered:

- the type of base vehicle
- the T&B vehicle configuration
- the T&B vehicle operation

These variances will impact the operational situations, hazardous events, and the S, E and C classifications.

System-Level Validation Environment — Since the safety goals are validated for the item in a representative context at the vehicle level, different base vehicle types in the case of T&B could be the subject of a safety validation.

Operation, Service and Decommissioning — The operation, service and decommissioning of the item is required to be conducted and documented in accordance with the service plan, instructions for service, and instructions for decommissioning. Such a requirement is important for T&B, since elements of T&B can be remanufactured and corresponding plans and instructions can be modified. Therefore, it is required that all the right plans and instructions are maintained and documented.

9. Guidance on Semiconductor Development

With the introduction of the First Edition of ISO 26262, semiconductor manufacturers were not well versed in the area of automotive functional safety. This resulted in some confusion in the early application of the standard to semiconductor components. A project

was launched within the working group developing ISO 26262 to assess and understand the impact of applying the standard to semiconductors. Two publicly available specifications were developed to address these issues [Refs. 8 & 9] and these became the origins of Part 11 in ISO 26262 Second Edition.

Part 11 of ISO 26262 Second Edition is an informative section and a necessary extension of the First Edition of ISO 26262 to provide guidelines for semiconductors used in automotive applications. This section provides guidelines on semiconductor components and semiconductor technologies. A semiconductor component can be developed as:

- **Part of the item** — In this case, the safety analysis performed per the product development at the hardware level applies, or
- **A Safety Element out of Context (SEooC)** — In this case, the development is assumed to meet a given ASIL independent of an item and its safety goals, and is based on assumptions to be verified at integration. If these assumptions are indeed verified, then the SEooC can be integrated into an item without further safety analyses.

10. Summary

In this paper, we summarized the content of the Second Edition of the ISO 26262 standard, including its scope of applicability, definitions, and requirements per its core and supporting processes, as well as some guidelines provided for semiconductor development. While presenting the summary, a few major modifications and additions were discussed. This summary is intended to be informative and is not intended to be a substitute for reading the standard in order to apply it. ●

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