

(R) Handbook for Robustness Validation of Automotive Electrical/Electronic Modules

RATIONALE

In late 2006 Members of the SAE International Automotive Electronic Systems Reliability Standards Committee and ZVEI (German Electrical and Electronic Manufacturers' Association) formed a joint task force to update SAE Recommended Practice J1211 NOV1978 "Recommended Environmental Practices for Electronic Equipment Design." The 1978 version of SAE J1211* was written in an era when electronics were first being introduced to the automobile. There was a high level of concern that the harsh environmental conditions experienced in locations in the vehicle could have a serious negative affect on the reliability of electronic components and systems. Some early engine control modules (ECMs) had failure rates in the 350 failures per million hours ($f/10^6$ hrs) range, or expressed in the customer's terms, a 25% probability of failure in the first 12 months of vehicle ownership. At that time, warranty data was presented in R/100 (repairs per 100 vehicles) units, for example, 25 R/100 at 12 months.

In these early years, when the automotive electronics industry was in it's infancy, a large percentage of these were "hard" catastrophic and intermittent failures exacerbated by exposure to environmental extremes of temperature (-40°C to $+85^{\circ}\text{C}$); high mechanical loads from rough road vibration and rail shipment; mechanical shocks of up to 100g from handling and crash impact; severe electrical transients, electrostatic discharge and electromagnetic interference; large swings in electrical supply voltage; reverse electrical supply voltage; and exposure to highly corrosive chemicals (e.g., road salt and battery acid). The focus of the 1978 version of J1211 was on characterizing these harsh vehicle environment for areas of the vehicle (engine compartment, instrument panel, passenger compartment, truck, under body, etc.) and suggesting lab test methods which design engineers could use to evaluate the performance of their components and systems at or near the worst-case conditions expected in the area of the vehicle where their electrical/electronic components would be mounted. By testing their prototypes at the worst case conditions (i.e., at the product's specification limits) described in the 1978 version of J1211 designers were able to detect and design out weaknesses and thereby reduce the likelihood of failure due to environmental factors.

By the mid-1980s, it became common practice to specify "test-to-pass" (zero failures allowed) environmental conditions-based reliability demonstration life tests with acceptance levels in the 90% to 95% reliability range (with confidence levels of 70% to 90%). This translates to approximately 5 to 20 $f/10^6$ hrs. The sample size for these tests was determined using binomial distribution statistical tables and this would result in a requirement to test 6 to 24 test units without experiencing a failure. If a failure occurred, the sample size would have to be increased and the testing continued without another failure till the "bogie" was reached. The environmental conditions during the test were typically defined such that the units under test were operated at specification limits based on J1211 recommended practices (e.g., -40°C and $+85^{\circ}\text{C}$) for at least some portion of the total test time. The "goal" of passing such a demonstration test was often very challenging and the "test-analyze-fix" programs that resulted, although very time-consuming and expensive, produced much-needed reliability growth. Reliability improved significantly in the late 1980s and early 1990s and vehicle manufactures and their suppliers began expressing warranty data in R/1000 units instead of R/100 units.

By the turn of the century automobile warranty periods had increased from 12 months to 3, 4, 5 (and even 10 years for some systems) and most manufacturers had started specifying life expectancies for vehicle components of 10, 15 and sometimes 20 years. And by this time several vehicle manufacturers and their best electrical/electronic component suppliers had improved reliability to the point where warranty data was being expressed in parts-per-million (ppm) in the triple, double and even single-digit range. This translates to failure rates in the $0.05 f/10^6$ hrs range and better! The achievement of such high reliability is not the result of test-to-pass reliability demonstration testing based on binomial

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distribution statistical tables. With this method, reliability demonstration in the 99.99% to 99.9999% range would require thousands of test units! On the contrary, the methods and techniques used by engineering teams achieving such reliability excellence did not require increasingly large sample sizes, more expensive and lengthy testing, or more engineers. It is about working smarter, not harder; and about systems-level robust design and robustness validation thinking rather than component-level “test-to-pass” thinking.

The task force leaders and members were of the strong opinion that the 2008 version of SAE J1211 should document the state-of-the-art methods and techniques being used by leading companies and engineering teams to achieve ultra-high reliability while at the same time reducing overall cost life-cycle and shortening time-to-market. The SAE International Automotive Electronic Systems Reliability Standards Committee and ZVEI (German Electrical and Electronic Manufacturers' Association) are hopeful that this Handbook for Robustness Validation of Automotive Electrical/Electronic Modules will help many companies and engineering teams make the transition from the 1980s “cookbook” reliability demonstration approach to a more effective, economically feasible knowledge-based Robustness Validation approach.

* Relevant information and data from SAE J1211 NOV1978 is preserved in SAE J2837 “Environmental Conditions and Design Practices for Automotive Electronic Equipment: Reference Data from SAE J1211 NOV1978”

FOREWORD

The quality and reliability of the vehicles a manufacturer produces has become a deciding factor in determining competitiveness in the automotive industry. Achieving quality and reliability goals effectively and economically depends on fundamental knowledge of how to select and integrate materials, technologies and components into functionally capable and dependable vehicle systems and being able to assess whether acceptable levels of quality and reliability have been achieved as the design comes together, matures and transitions into a mass production environment.

Evaluation methods, whether physical or analytical, must produce useful and accurate data on a timely basis in order to provide added value. Increasingly, manufacturers of automotive electrical and electronic (E/E) equipment must be able to show that they are producing a product which performs reliably in applications having defined mission profiles.

Reliability is a measure of conditional probability that a product will perform in accordance with expectations for a predetermined period of time in a given environment under defined usage conditions. To efficiently meet any reliability objective requires comprehensive knowledge of the relationships between failure modes, failure mechanisms and mission profile. Gradual reliability growth by repeated test-analyze-fix cycles is no longer sufficient or competitive (see Rationale).

Ten years ago the prevailing philosophy was: “Qualification tests of production validation units must ensure that quality and reliability targets have been reached.” This approach is no longer sufficient to guarantee robust electronic products and a failure free ownership experience for the life of the car, i.e., a philosophy of the Zero-Defect-Strategy. The emphasis has now shifted from the detection of failures at the end of the development process to prevention of failures throughout the full life cycle, beginning with concept development and requirements specification.

In the past, screening methods were still required after the product had been manufactured and after the product had successfully passed a qualification program. In recent years the emphasis has shifted to reliability-by-design methodologies applied during development. The philosophy of Robust Design has been widely accepted and the number methods, tools and techniques to support the approach have been increasing steadily.

The fundamental philosophy of product qualification is also changing from the detection of defects based on predefined sample sizes to the generation and reuse of knowledge gained by studying specific data regarding the product's failure modes and mechanisms combined with existing knowledge in the field. Using these methods, known as “physics of failure” or “reliability physics” it is possible to generate highly useful knowledge on the robustness of products.

This handbook is intended to give guidance to engineers on how to apply a robustness validation process during development and qualification of automotive electrical/electronic modules. It was made possible because many companies, including electronic/equipment manufacturers and vehicle manufacturers worked together in a joint working group to bring in the knowledge of the complete supply chain.

This handbook is synchronized with its European counterpart document “Handbook for Robustness Validation of Automotive Electrical/Electronic Modules” published by the German Electrical and Electronic Manufacturers' Association (ZVEI) www.zvei.org/ecs, Frankfurt, 2008.

Software Robustness is not specifically addressed in this document. However some degree of software evaluation is addressed by the test methods. Some examples are:

- Testing the module in a sub-system configuration if possible.
- Testing the module with realistic loads.
- Exercising the module in various modes during a test.

Also, although this handbook is directed primarily at electrical/electronic “modules” it may certainly be applied to other equipment such as sensors, actuators and mechatronics.

INTRODUCTION

This Robustness Validation Handbook provides the international automotive electronics community with a common knowledge-based qualification methodology based on the philosophy of robust design. Robustness Validation activities begin in the product conceptualization phase and continue throughout the full life cycle of the product. By integrating robust design and robustness validation with systems engineering practices, project teams are able to design-in and demonstrate product reliability for the user’s intended application(s).

This handbook defines a methodology to assess the Robustness Margin of an electrical/electronic module. Robustness Margin is defined as the margin between the outer limits of the modules specification and the actual performance capability of the mass-produced product considering all significant source of variation. The task of determining Robustness Margin is started during the design and development process and continues throughout the production life using monitoring mechanisms. It is in this manner that reliability is assured throughout the life cycle of the product.

This Robustness Validation Handbook defines a Robustness Validation process in which the user and the supplier of the electrical/electronic module establish requirements and acceptance criteria based on a defined Mission Profile and reliability performance requirements for the vehicle application(s). The objective of Robustness Validation process is to design-out susceptibility to failure mechanisms, assess whether the Robustness Margin is sufficient for the intended application(s), and develop inherently robust manufacturing and assembly processes capable of producing zero-defect product.

Robustness Validation relies first on knowledge-based modeling simulation and analysis methods to develop a highly capable design prior to building and testing physical parts; and then on test-to-failure (or acceptable degradation) and failure/defect susceptibility testing to confirm or identify Robustness Margins, to enable failure prediction and verify that manufacturing processes produce defect free parts. These techniques represent advancement beyond “test-to-pass” qualification plans which usually provide very little useful engineering information about failure modes, failure mechanisms and failure points.

Robust design concepts provide an efficient way to optimize a product in light of the “real world” operating conditions it will experience. Validation is a process for evaluating a product’s suitability for use in its intended use environment. Thus it is natural that robustness and validation go hand-in-hand. To achieve efficiency, robustness relies on up front use of “physics-of-failure” knowledge and tools, fundamental principles of statistical experimentation, and techniques and tools like FMEA, P-Diagrams, orthogonal arrays and Response Surface Methodology. However, the objective of robustness is not merely to complete a design of experiments (DOE), but to understand how the product or process performs its intended function within, and at the limits of, the user specifications.

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1. SCOPE

This document addresses robustness of electrical/electronic modules for use in automotive applications. Where practical, methods of extrinsic reliability detection and prevention will also be addressed. This document primarily deals with electrical/electronic modules (EEMs), but can easily be adapted for use on mechatronics, sensors, actuators and switches. EEM qualification is the main scope of this document. Other procedures addressing random failures are specifically addressed in the CPI (Component Process Interaction) section 10. This document is to be used within the context of the Zero Defect concept for component manufacturing and product use.

It is recommended that the robustness of semiconductor devices and other components used in the EEM be assured using SAE J1879 OCT2007, Handbook for Robustness Validation of Semiconductor Devices in Automotive Applications.

The emphasis of this document is on hardware and manufacturing failure mechanisms, however, other contemporary issues as shown in Figure 1 need to be addressed for a thorough Robustness Validation. A Pareto of contemporary issues is shown in Figure 1. Although this document addresses many of the issues shown, however some are outside the scope of this document and will need to be addressed for a thorough RV process application. Examples of issues outside the scope of this document are system interactions, interfaces, functionality, HMI (Human-Machine Interface) and software. At the time of publication of this handbook, a system level Robustness Validation handbook, which addresses these issues, had been initiated.

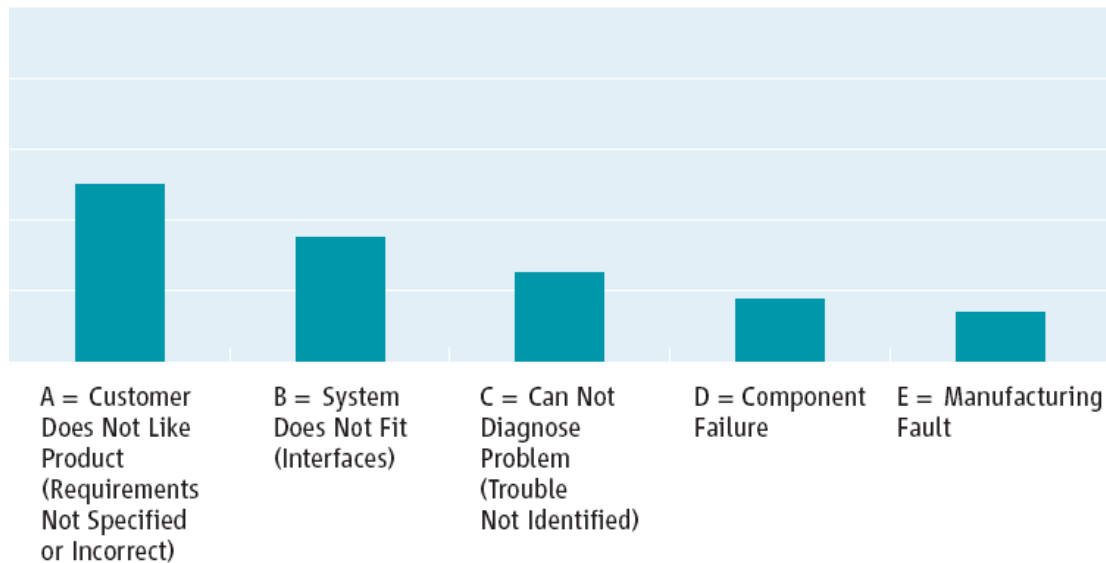


FIGURE 1 - RELATIVE CONTRIBUTIONS OF ISSUES WITH E/E SYSTEMS AT VEHICLE LEVEL [9]

1.1 Purpose

This Robustness Validation Handbook provides the automotive electrical/electronics community with a common qualification methodology to demonstrate robustness levels necessary to achieve a desired reliability.

The Robustness Validation approach emphasizes knowledge based engineering analysis and testing a product to failure, or a predefined degradation level, without introducing invalid failure mechanisms. The approach focuses on the evaluation of the Robustness Margin between the outer limits of the customer specification and the actual performance of the component. These practices integrate robustness design methods (e.g., test-to-failure in lieu of test-to-pass) into the automotive electronics design and development process. With successful implementation of robustness validation practices, the producer and consumer can realize the objectives of improved quality, cost, and time-to-market.

The purpose of this Robustness Validation Handbook is to establish globally accepted concepts, processes, methods, techniques and tools for implementing the Robustness Validation qualification methodology for automotive electrical/electronic modules (EEM) and systems.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

SAE J1213-2 Glossary of Reliability Terminology Associated with Automotive Electronics

SAE J1739 Potential Failure Mode and Effects Analysis in Design (Design FMEA) and Potential Failure Mode and Effects Analysis in Manufacturing and Assembly Processes (Process FMEA) and Effects Analysis for Machinery (Machinery FMEA)

SAE J1879 Handbook for Robustness Validation of Semiconductor Devices in Automotive Applications

SAE J2628 Characterization, Conducted Immunity

2.1.2 Other Publications

- [1] Porter, Alex, Accelerated Testing and Validation: Testing, Engineering, and Management Tools for Lean Development, Elsevier Science & Technology Inc., Burlington, MA 1984.
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- [10] SAE G-11 Reliability, Maintainability, and Supportability Guidebook, 3rd Edition, SAE Inc., Warrendale, PA, 1995.
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- [20] SAE G-11 Reliability, Maintainability, and Supportability Guidebook, 3rd Edition, pg. 261-264, 1995, Warrendale, PA, SAE, Inc.
- [21] Zero Defect Strategy - ZVEI Revision 1, January 2007.
- [22] SAE J2837 - Environmental Conditions and Design Practices for Automotive Electronic Equipment: Reference Data from SAE J1211 NOV1978

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

Madhav S. Phadke, iSixSigma LLC: "Introduction to Robust Design-Robustness Strategy"

Dr. Ing. Werner Kuitsch: "Umweltsimulation von Schwingungs- und Stoßbelastungen", lecture at Technische Akademie Esslingen, 2004

Microelectronic Reliability, Volume II: Integrity Assessment and Assurance, edited by E. Pollino, Artech House Publishers, ISBN 0-890-06350-8, 1989

JEDEC-020D Handling of Moisture Sensitive Devices

The Design Analysis Handbook, Edward Walker, ISBN 0-7506-9088-7

Noise Reduction Techniques in Electronic Systems, Henry Ott, ISBN 0-471-85068-3

Williams et al, An Investigation of "Cannot Duplicate" Failures. Quality and Reliability Engineering Journal Vol. 14, Issue 5, pp. 331-337 John Wiley & Sons, 24 Dec 1998

IEC 60300-1 Dependability management – Part 1: Dependability management systems, International Electrotechnical Commission, June 2003"

MIL-STD-810, Environmental Engineering Considerations and Laboratory Tests

3. DEFINITIONS

3.1 DEFINITION OF TERMS

3.1.1 Accelerated Test

An accelerated test is designed to identify failures or produce degradation in a shortened period or time.

3.1.2 Acceleration Factor

Acceleration factor is the ratio between the times necessary to produce the same degradation or failure mechanism in an accelerated test compared to the use conditions.

3.1.3 Component

Component is a parts required for the function of an electrical/electronic module. Examples include capacitors, resistors, ASICs, power-MOSFET, connectors, fasteners and mechatronic assemblies.

3.1.4 Defect

A defect is a deviation in an item from some ideal state. The ideal state is usually given in a formal specification.

3.1.5 Degradation

Degradation is a gradual deterioration in performance as a function of time.

3.1.6 Derating

Derating is the intentional reduction of stress/strength ratio in the application of an item, usually for the purpose of reducing the occurrence of stress related failures.

3.1.7 Design Validation

Design validation is a set of tests or analyses performed to demonstrate that a component or systems is suitable for its intended use and meets known customer/application validation requirements.

3.1.8 Design Verification

Design verification is a set of tests or analyses performed to demonstrate that a component or system has the potential to meet its specified design requirements

3.1.9 ECU (Electronic Control Unit)

The ECU is an electrical stand-alone module or modules with electrical and/or optical interface. The ECU typically consists of housing, connector, conductor boards and electrical components. An example is a Motor management system.

3.1.10 Electrical/Electronic Module

The EEM is an electrical alone module or modules with electrical and/or optical interface. The EEM typically consists of housing, connector, conductor boards and electrical components. An example is a motor management system. Mechatronics integrate mechanical and electrical functions into one unit. The mission profile of this solution has to take into account the requirements of both the mechanical and electrical parts. In vehicle applications typical mechatronic products cannot be exchanged independently from electronics. Typical examples include ABS, EPS (Anti-Lock Braking System, Electrical Power Steering).

3.1.11 Failure

Failure is the loss of ability of an EEM to meet the electrical or physical performance specifications that it was intended to meet.

3.1.12 Failure Mechanism

A failure mechanism is the process or sequence of processes (mechanical, chemical, electrical, thermal, etc.) that produces a condition that results in a failure or fault.

3.1.13 Failure Mode

A failure mode is the manner in which a failure, or fault condition is perceived or detected.

3.1.14 FMEA, (Failure Mode and Effects Analysis)

An FMEA is a qualitative and consensus based disciplined analysis of possible failure modes on the basis of seriousness, probability of occurrence and likelihood of detection.

3.1.15 Load

A mechanical load is an externally applied and internally generated force that acts on a system or device. The application of loads results in stress and strain responses within the structures and materials of the system or device. Loads may be acoustic, fluid, mechanical, thermal, electrical, radiation or chemical in nature.

3.1.16 Load Distribution

A load distribution is a statistically described load level over time, cycles, temperature, voltage, climatic conditions, or other load types.

3.1.17 Mechatronic Module

A mechatronic module integrates mechanical and electrical/electronic functions.

3.1.18 Mission Profile

A mission profile is a simplified representation of relevant conditions to which the EEM production population will be exposed in all of their intended application throughout the full life cycle of the component.

3.1.19 Model

A model is a simplified scientific representation of a system or phenomenon, in which a hypothesis (often mathematical in nature) is used to describe the system to explain behavior.

3.1.20 Operating Conditions

Operating conditions are environmental parameters such as voltage bias, and other electrical parameters whose limits are defined in the datasheet and within which the device is expected to operate reliably.

3.1.21 Product Life Cycle

The product life cycle is the time period from the beginning of the manufacturing process of the electrical/electronic module to the end of life of the vehicle.

3.1.22 Qualification

A qualification is a defined process by which a product or production technology is examined and tested, and then identified as qualified.

3.1.23 Random Failure

A random failure or fault which occurs in a statistically random fashion.

3.1.24 Reliability

Reliability is the ability of a system or component to perform its required functions under stated conditions for a specified period of time.

3.1.25 Robustness

Robustness is an insensitivity to noise (i.e., variation in operating environment, manufacture, distribution, etc., and all factors and stresses in the product life cycle).

3.1.26 Robustness Validation

A robustness validation process demonstrates that a product performs its intended function(s) with sufficient margin under a defined mission profile for its specified lifetime. It requires specification of requirements based on a mission profile, FMEA to identify the potential risks associated with significant failure mechanisms, and testing to failure, "end-of-life" or acceptable degradation to determine robustness margins. The process is based on measuring and maximizing the difference between known application requirements and product capability within timing and economic constraints. It encompasses the activities of verification, legal validation, and producer risk margin validation.

3.1.27 Simulation

Simulation is the representation of the behavior or characteristics of one system through the use of another system, especially with a computer program designed for the purpose of simulating an event or phenomenon. The technique of representing the real world by a computer program, such that the internal processes of a system, are emulated as accurately as is possible or practical and not merely mimicking the results of the thing being simulated.

3.1.28 Stress Factor

A stress or combination of stresses triggering a failure mechanism.

3.1.29 System

A set/combination of several EEMs / Mechatronics or sensors / actuators, connected to perform a distributed functionality is shown in Figure 2.

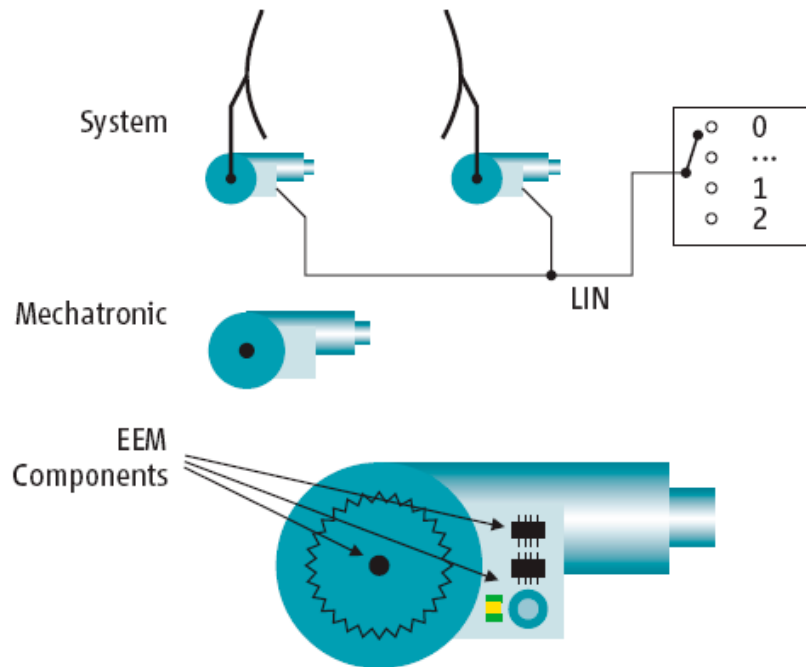


FIGURE 2 - EXAMPLE OF SYSTEM, MECHATRONIC AND COMPONENTS

3.1.30 Systemic Failure

A systematic failure is a non-random failure caused by an error in any activity which, under some particular combination of inputs or environmental conditions, will cause failure. For example, an incorrectly rated resistor may result in systematic failure.

3.1.31 Temperatures

To describe the thermal conditions in the EEM / mechatronic and the semiconductor components inside the EEM, the temperatures at the points defined in Figure 3 can be used. The definitions of these temperatures are:

- T_{Vehicle} Mounting Location Ambient: Temperature at 1 cm distance from the EEM package.
- T_{EEM} Package: Temperature at the EEM package.
- T_{EEM} internal: Temperature of the free air inside the EEM.
- $T_{\text{Comp.package}}$: Temperature at the component package.
- $T_{\text{Comp.Pins}}$: Temperature at the component pins.
- T_{Junction} : Junction temperature of the component chip (or substrate).

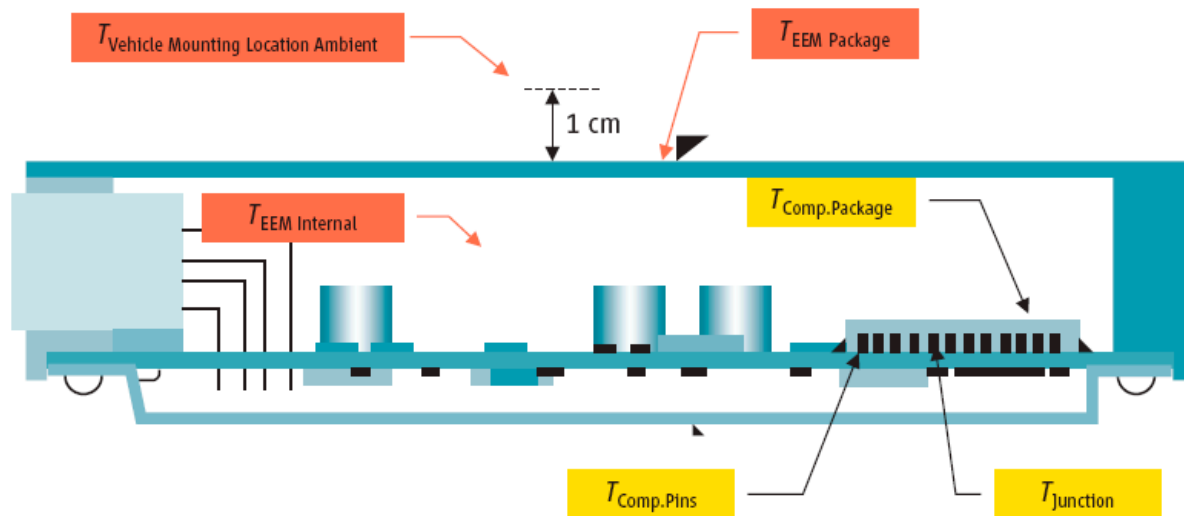


FIGURE 3 - EEM TEMPERATURE MEASUREMENT POINTS

The OEM relevant temperature for mission profiling is: $T_{\text{vehicle mounting location Ambient}}$
 In mechatronic systems additional heat sources or sinks have to be considered (e.g., coolant, engine block...)

3.1.32 Trouble Not Identified (TNI)

The Customer Declared Failure could not be duplicated or identified.

3.1.33 Vehicle

The vehicle is the automobile.

3.1.34 Vehicle System

A system on a vehicle, is made up of several interconnecting modules or mechanics.

3.1.35 Verification

The conclusion of the primary product development learning process supporting progress to the legal validation phase that the product has a high probability for meeting all known application requirements. There are no legal ramifications in verification. Learning may occur with test to failure for capability measurement beyond the established requirements and reliability demonstration

3.1.36 Validation

The process of accumulating evidence to support a declaration with legal force that a system/module/component meets the known application requirements. Validation culminates in producing a formal declaration with legal weight that a product has been confirmed supported by objective evidence that the requirement for a specific intended use have been fulfilled. Tests have a defined success point that becomes the base measurement for the “Robust Validation” phase.

3.1.37 Virtual Entity

An item that is not physically real, but displays the qualities of reality or exists in a potential state that could become realized and is often represented in a simulation model.

3.1.38 Wear-Out Failure

A wear-out failure caused by accumulation of damage due to loads (stresses) applied over an extended period of time.

3.1.39 Zero Defect Strategy

Zero Defect is a management approach (also described as a fashion, mindset or culture), which does not mean zero defects in a literal of statistical sense. Rather, it is a value chain activity which makes attempts in its approach and methods to achieve Zero Defects with the design goal to manufacture a product with the minimum defects possible.

3.2 Acronyms

AMS	Analysis Modeling and Simulation
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CD	Continuous Duty
CPI	Component-Process Interaction
Cpk	Process Capability Index
Cmk	Machine Capability Index
DBTF	Design - Build - Test - Fix
DPMO	Defects Per Million Operations
DUT	Device Under Test
DV	Design Validation
D & V	Development and Validation
DVP&R	Design Validation Plan and Report.
ECU	Electronic Control Unit
E/E	Electrical/Electronic
EEM	Electrical/electronic module
ESD	Electrostatic

EMC	Electro Magnetic Compatibility
HALT	Highly Accelerated Life Test
IEC	International Electro technical Commission
I/O	Input / Output
M&S	Modeling and Simulation
PCB	Printed Circuit Board
PoF	Physics of Failure
PV	Production Validation
QRD	Quality/Reliability/Durability
R	Reliability
RIF	Robustness Indication Figure
RFA	Remote Function Actuation
RKE	Remote Keyless Entry
RV	Robustness Validation
SOR	Statement of Requirements
SPC	Statistical Process Control
SS	Steady State
TNI	Trouble Not Identified
T _g	Glass Transition Temperature
T _{max}	Temperature Maximum
T _{min}	Temperature Minimum.

4. DEFINITION AND DESCRIPTION OF ROBUSTNESS VALIDATION

4.1 Definition of Robustness Validation

Robustness Validation is a process to demonstrate that a product performs its intended function(s) with sufficient robustness margin under a defined mission profile for its specified lifetime. It should be used to communicate, analyze, design, simulate, produce and to test an EEM in such a manner, that the influence of noise (or an unforeseeable event) on an EEM is minimized.

Robustness Validation can and should be applied for developments of different types, completely new, incremental change or modifications when evaluating the different types of development projects account should be taken of previous knowledge and lessons learned.

4.2 Robustness Validation Process

A robust product is one that is sufficiently capable of functioning correctly and not failing under varying application and production conditions. The Robustness Validation process defined in this handbook relies heavily on team expertise and knowledge, and therefore requires detailed explanation and intensive communication between the user and supplier.

The Robustness Validation flow shown in Figure 4 is an essential part across the development process. This method is based on three key components:

- Knowledge of the conditions of use (mission profile).
- Knowledge of the failure mechanisms and failure modes and the possible interactions between different failure mechanisms.
- Knowledge of acceleration models for the failure mechanisms needed to define and assess accelerated tests.

Robustness validation is a knowledge-based approach [1, 2] that uses analytical methods and stress tests that are defined to address specific failure mechanisms using suitable models, test and stress conditions. This approach results in a product being qualified as “fit for use”, not “fit for standard”.

It is important to note, that as Robustness Validation is a knowledge based approach it must not be applied blindly, or in a standardized default manner as current Verification approaches, but with appropriate experience and training of the people applying the process and of the failure mechanisms. The RV users own knowledge matrix (see Section 7) must be a central part of the RV process within an organization.

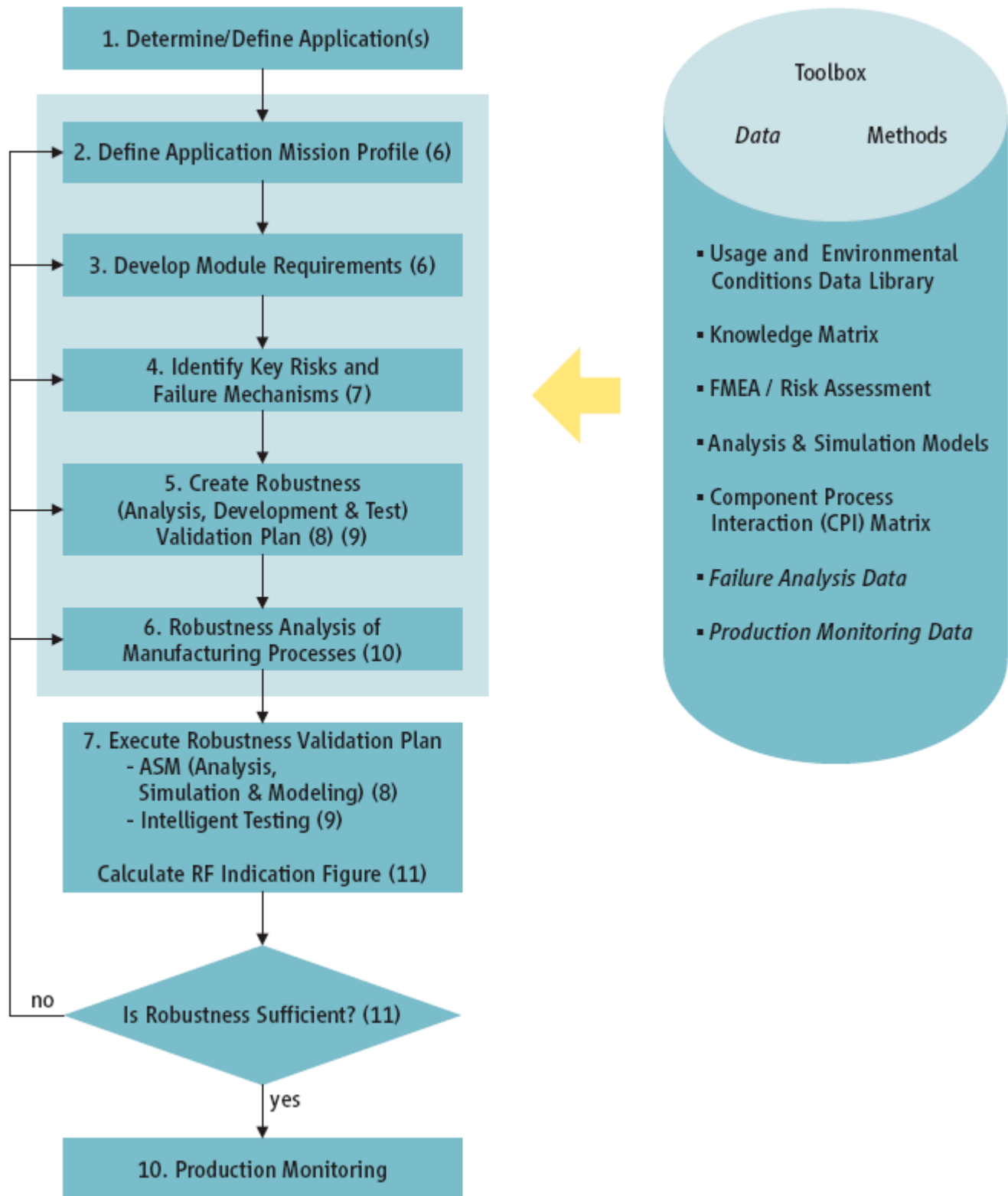


FIGURE 4 - THE ROBUSTNESS VALIDATION PROCESS FLOW

When considering the RV process the standard V model concept should be applied at each level/stage of the RV process from the top (System) level to the bottom (Component) and back up again with repeated iterations and feedback up and down the process chain.

The V-model in Figure 5 shows the concept of requirement flowing from the customer, to the vehicle, to the system, to the module, and to components. The sources of requirements should be documented. Module design concepts need verification which involves sharing and documenting information between the OEM and suppliers at all levels. Once a requirement is accepted, it needs validation to determine if the requirement is satisfied.

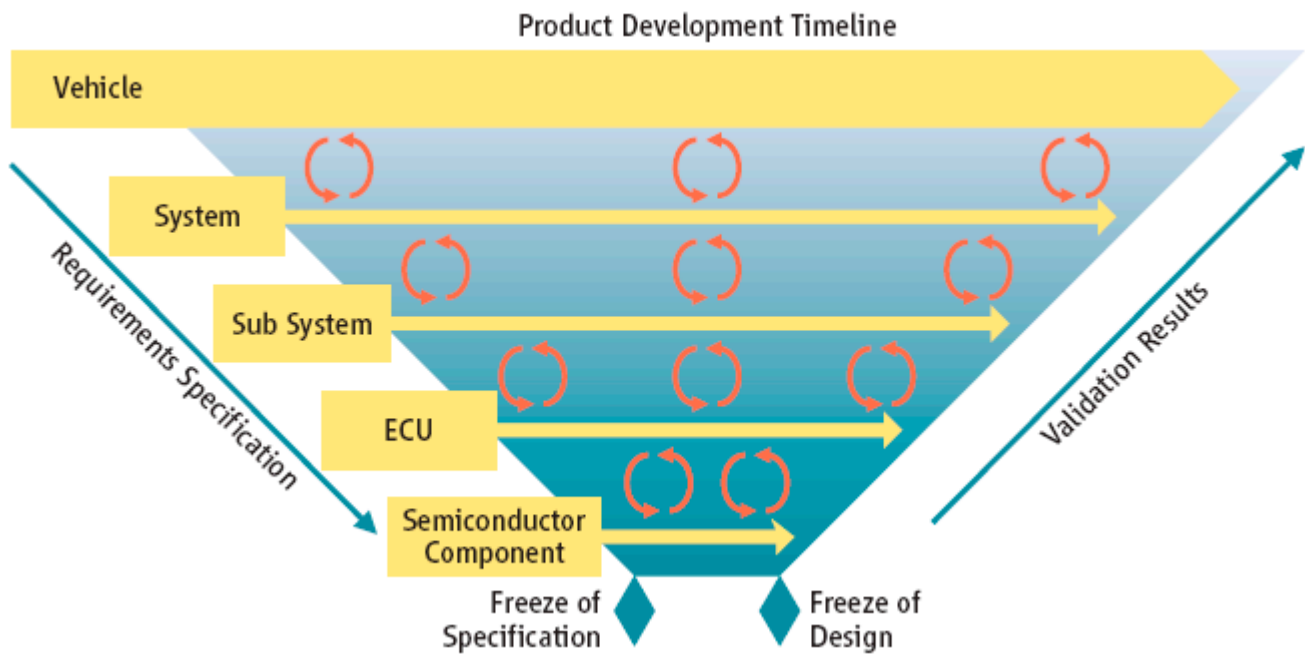


FIGURE 5 - THE AGILE PRODUCT DEVELOPMENT PROCESS

5. INFORMATION AND COMUNICATION FLOW

The efficiency and effectiveness of Robustness Validation largely depends on communication of previous and ongoing learning that takes place between the individuals, teams and organizations involved in the module's design, development, validation, production and use. As seen in Figure 6.

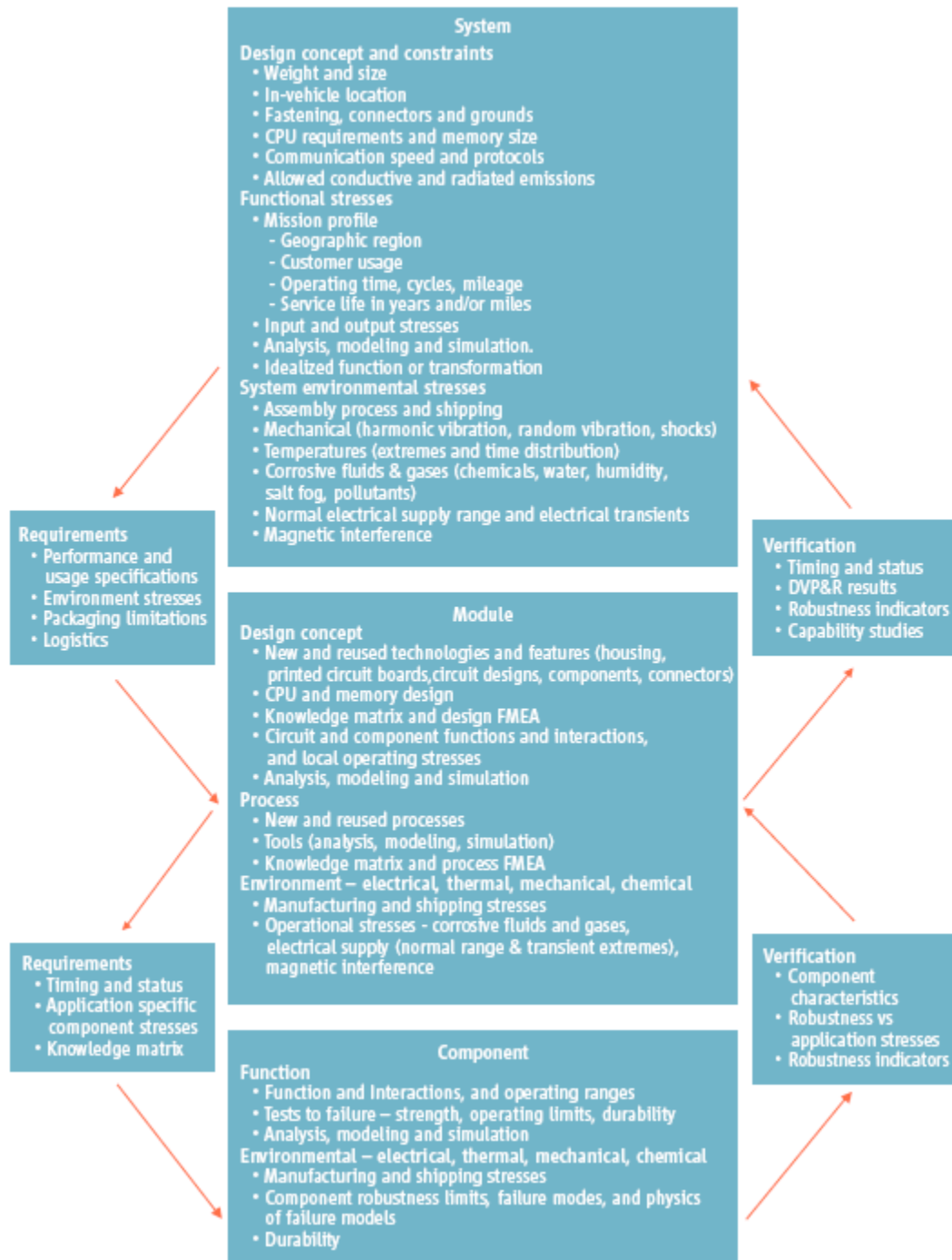


FIGURE 6 - ROBUSTNESS VALIDATION INFORMATION FLOW

5.1 Product Requirements

Modules are expected to support requirements that are developed from the mission profile which considers different aspects of the module's intended function, environments, and service life targets. There are different sources of these requirements, i.e., the vehicle user, regulatory agencies, market consideration, local environments, dealer service, vehicle and parts shipping and storage, vehicle assembly, mounting location in the vehicle, and other OEM requirements. The requirements flow from these sources to the vehicle, to the system, and finally to the module.

A boundary diagram shows as inputs to the module customer, regulatory, and assembly requirements plus "involved" modules that interface to the device. Some requirements are subjective and difficult to capture as a measurement parameter. The boundary diagram in Figure 7 is a useful tool to assure these requirements are captured.

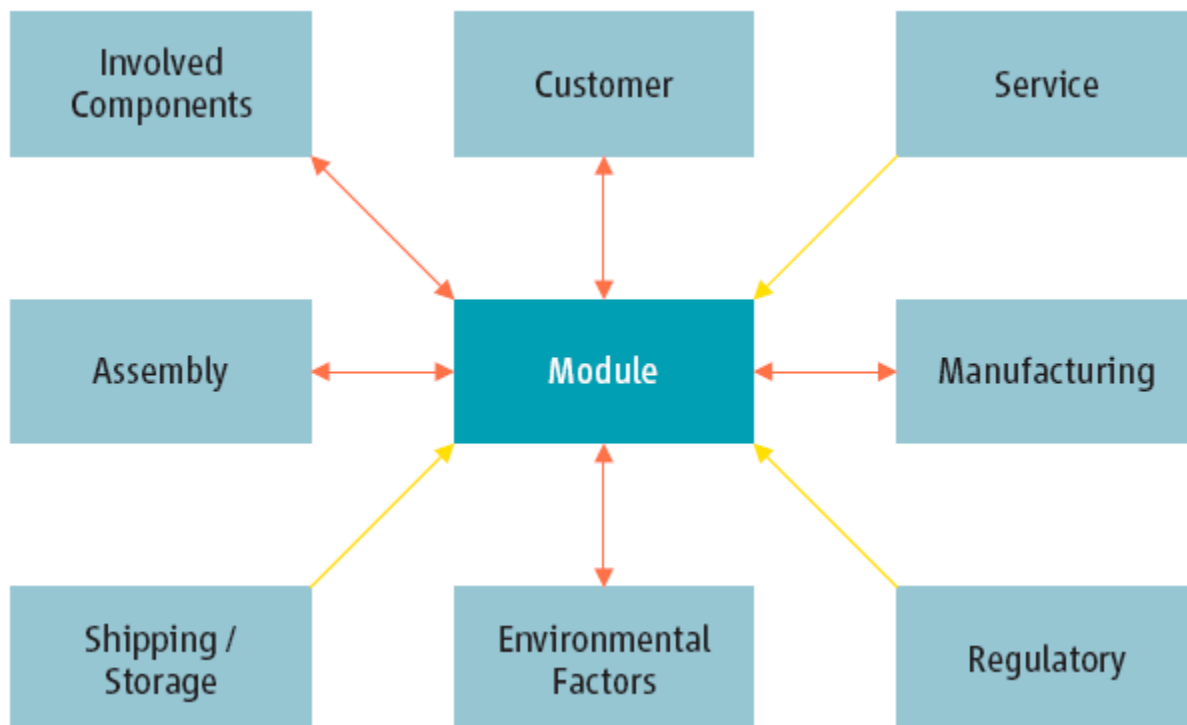


FIGURE 7 - BOUNDARY DIAGRAM

The Parameter Diagram (P-diagram) in Figure 8 captures and summarizes inputs, outputs, environmental stresses, and design constraints for products. A device, represented by a box at the center of the diagram, may be a component, module, system, or vehicle. By convention, inputs are listed on the left with arrows leading into the box; outputs, on the right with arrows leading from the box; environmental stresses, on the bottom with arrows leading to the box; and design constraints, above the box with arrows leading to the box.

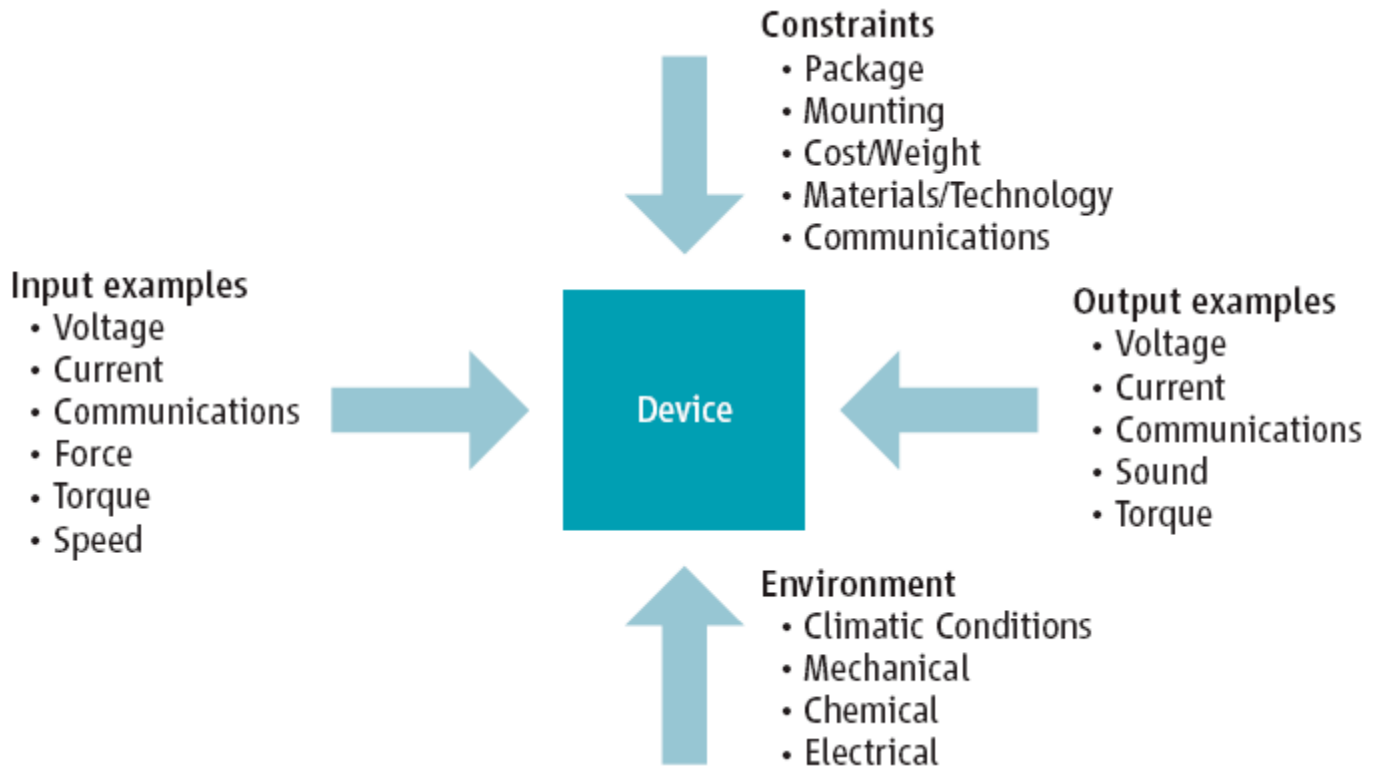


FIGURE 8 - MODULE PARAMETER DIAGRAM (P-DIAGRAM)

5.2 Use of Available Knowledge

Most electronic modules are evolutionary development of past modules and use similar design and manufacturing concepts. There is a high level of reuse of individual components, circuit designs, connectors and housing concepts. In vehicles, the modules perform similar functions and share similar locations. Around 90% of a new module design is similar to some predecessor module. However, the changes that occur may include the addition of functions to a module, some new circuits, new board layouts to accommodate the new circuits, and technology changes of components. Also, the vehicle environment may become more severe.

Traditionally, module verification and validation focused on repeating a standard suite of tests with the addition or deletion of functional tests. Similarly, environmental stress tests were repeated with every new module. As electronic modules become more complex, the potential number of combinations and permutations of operating modes and associated functional tests becomes very large with associated very expensive long duration tests. A more efficient process is required that focuses verification and validation on **changes** and **potential interactions of the changes** with other module functions.

How does one manage this process? The design and process reviews are appropriate forums. The first topic should be the predecessor design. What were the problems and lessons learned? Are their symptomatic warranty, vehicle assembly, manufacturing, and shipping/storage issues? The new design should include changes to correct these issues, i.e., support continuous improvement. The new features need to be reviewed. The new features, old module improvements, and technology changes constitute the scope of the change verification. The risk associated with these changes should be addressed in Design and Process FMEAs. High risk items and functional validation need to be included in a test plan. The Robustness Validation plan should be integrated in the DVP&R.

6. MISSION PROFILE

The Mission Profile is a representation of all relevant conditions an electrical/electronic module will be exposed to in all of its intended applications throughout its entire life cycle. It is therefore important that the Mission Profile for each individual electrical/electronic module be developed and communicated to the engineers designing the module as soon as possible. With a good description of the Mission Profile, engineers can begin to estimate reliability and quality levels and start to work toward achieving 'zero defects' and robust design at all levels of the supply chain.

This section provides an overview of the various conditions and stress factors (loads) an electrical/electronic module may experience during its life cycle. This information is intended to be used as a starting point in developing Mission Profiles for individual electrical/electronic modules. Stress factors may be mechanical, climatic, chemical and electrical loads during manufacturing, operation, stand by operation, transport and car assembly. As shown in Figure 9, the stress factors may be due to environmental loads, functional loads or both simultaneously.

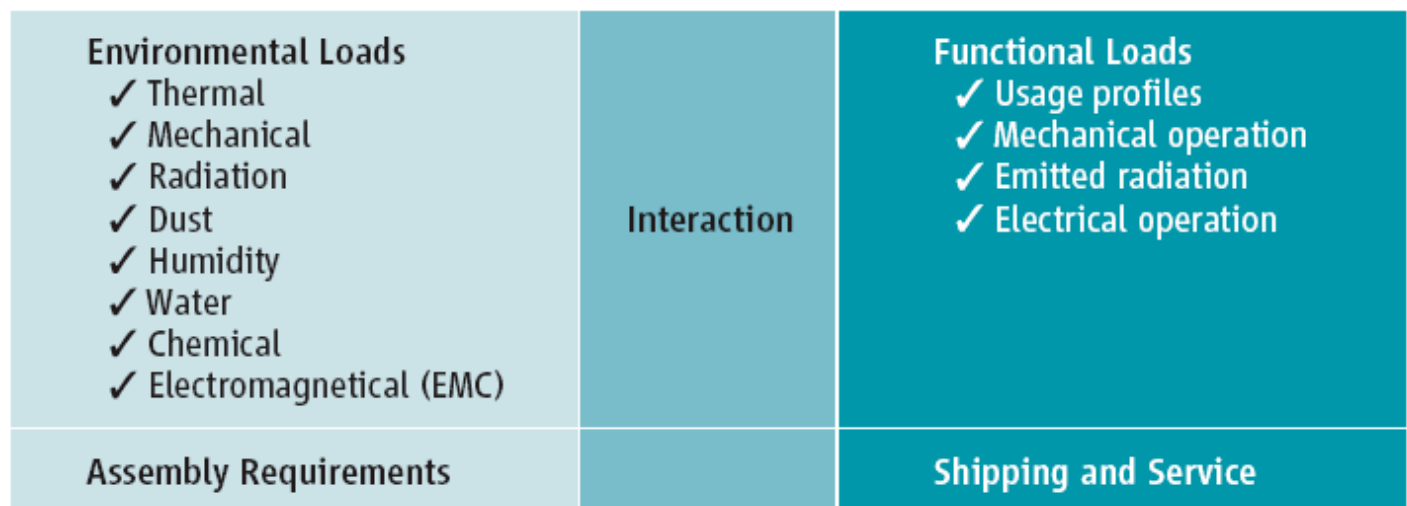


FIGURE 9 - ENVIRONMENTAL AND FUNCTIONAL LOAD STRESS FACTORS

As the product development process progresses, mission profiles and functional loads will be defined more precisely. Therefore changes and revisions to loads or load distributions shall be agreed upon between the parties.

The mission profile is not a test description. It is the basis for material selection, design, test engineering, parameterization, analysis, modeling and simulation, and robustness evaluation.

6.1 Process to Derive a Mission Profile

When developing a mission profile, using the process flow defined in Figure 10 it is likely that multiple sources of data will be utilized. In most cases a combination of publicly available [3, 22], private historical data and freshly generated data will be used. Knowledge of the conditions of use in the vehicle application(s) and the possible effects on the module and components is required. Because some factors may have little effect while other may have a strong effect, it is also necessary to judge the relevance of each factor.

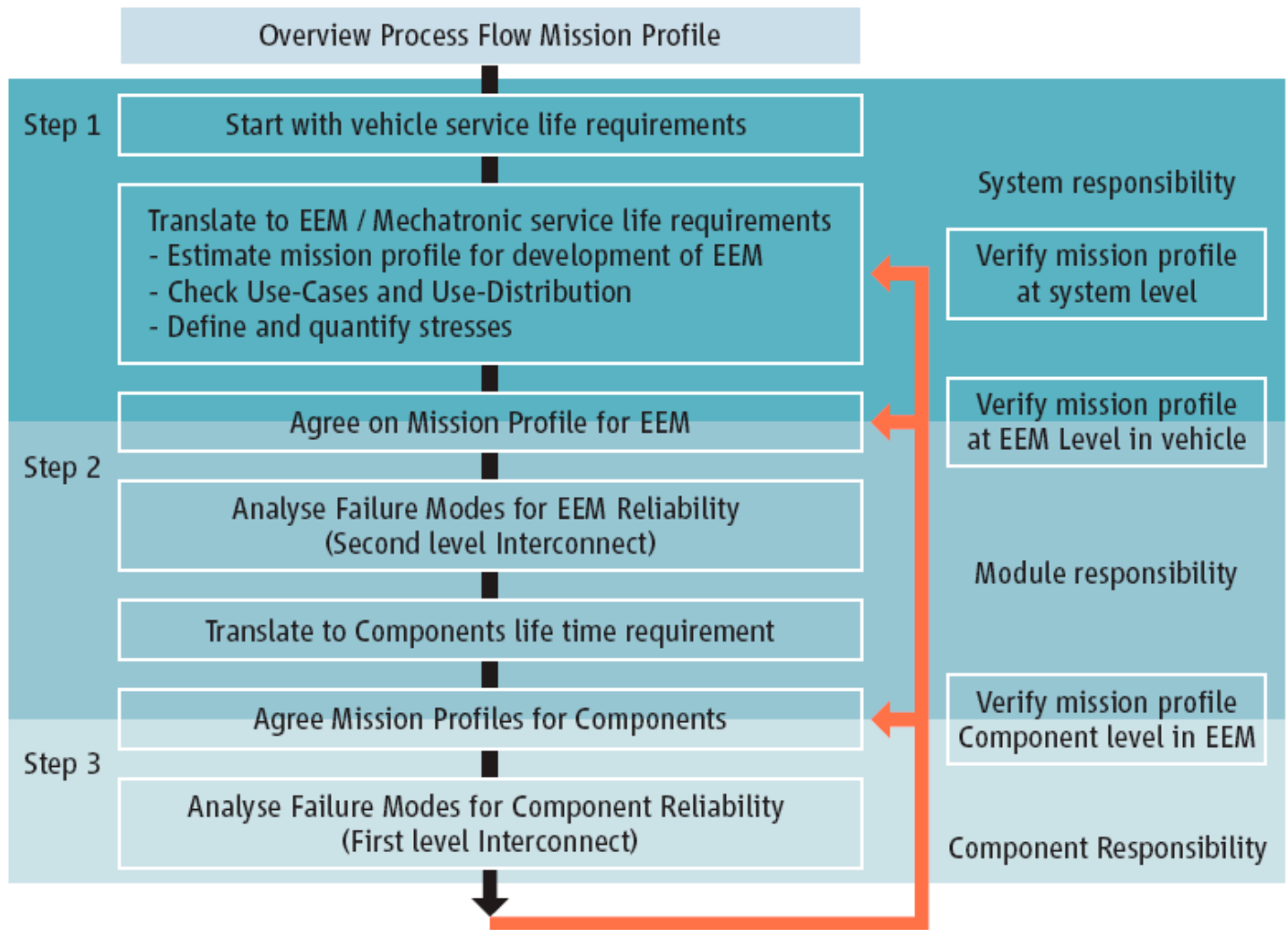


FIGURE 10 - OVERVIEW OF A PROCESS FLOW FOR GENERATING A MISSION PROFILE

STEP 1: Start with vehicle service life requirements. The most general data concern is the required vehicle service life. This comprises information for example:

- Service lifetime: The total lifetime of the car.
- Mileage: The total amount of miles/kilometers that the car is assumed to drive during its service life.
- Engine on time: The amount of time that the engine is switched on (key-on time) and operational during the service lifetime (if product is active during this time).

An example of this kind of data is given in Table 1 below.

TABLE 1 - EXAMPLE OF VEHICLE MISSION PROFILE PARAMETERS AT THE VEHICLE LEVEL

Service lifetime	15 years (= 131.400 h)	
Mileage	600.000 km	High level high mileage request for stand alone EEM (not for mechatronics)
Engine on time	12.000 h	Engine on time is directly proportional to mileage. Operating time of single component may be different than engine on time.
Engine on/off cycles	54.000	Without additional start/stop functions

STEP 2: Translate to EEM / Mechatronic life time requirements (OEM)

The above definitions are valid for the whole vehicle. However, depending on the functionality required, the active and passive periods may be very different for the vehicle versus the EEM. Their different service life requirements are exemplified in Table 2 below.

TABLE 2 - DIFFERENT SERVICE LIFE REQUIREMENTS FOR VEHICLE AND EEM

Vehicle	EEM
Engine on time	EEM on time (operating, active)
Engine off (non-operating time)	EEM off time (non-operating) EEM standby time
Engine on/off cycles	EEM on/off cycles

Furthermore, for the mission profile of the EEM, the mounting location and specific use cases have to be considered. Therefore, for each EEM / Mechatronics, the active, stand-by, sleep and non-operating time must be determined individually.

Step 2.1: Collect possible operating modes (active, stand-by, special loads, sleep, power supply interrupted, cyclically reoccurring operation, and operating mode changes)
Each relevant function must be completely covered.

Step 2.2: Assign operating modes to the defined vehicle lifetime requirements.

Step 2.3: Describe mounting locations, conditions and related loads:

- Temperature (Distribution)
- Temperature cycling (Distribution)
- Vibration (Distribution)
- Water, salt, dust, humidity, chemical agents
- Detail load profiles (e.g., electrical/thermal/mechanical loads) of the EEM/Mechatronic (experience from present projects).

Result: Basis for mission profile for EEM/mechatronic

Consider: Misuse, safety requirements, transport, storage, service (EOS/ESD), processing/assembly, testing.

An example of this kind of data for EEM level is given in Table 3 below.

TABLE 3 - EXAMPLE OF OEM EEM OPERATING LIFE TIME REQUIREMENTS

	Operating on Time (active) (h)	Non Operating Time (h)	EEM Active On/Off Cycles	EEM Specific Operating Load Cycles
Motor-management	12.000 + 3.000 Standby time	116.400	54.000 Without additional start/stop functions	Engine on/off...
Transmission control module	6.000	125.400		Gear shift...
Door Module	8.000	79.800	36.000 + operating cycles Operating cycles: + window + mirror activation	Window lift...

6.1.1 Estimation of Mission Profile for Development of EEM

A first set of mission profiles is necessary to derive requirements for use in the development process (temperature limits for component selection, etc.). It is likely that there is little or no data available at that time. However, an approximation can be given by:

- Use standard mission profiles for defined mounting location.
- Use measurements from previous developments.
- Use measurements from similar applications / vehicles.
- Estimate usage, generated by thinking possible use-cases through.

To make sure that all parameters of any adopted mission profile cover the requirement for the specific mounting location, a validation of the chosen mission profile for the specific application is necessary.

These estimates should be verified by actual measurements as parts / installations become available during the development process.

6.1.2 Check Use-Cases and Use-Distribution (Refinement and Validation)

Define Use-Cases – Use-cases can help identify sources of loads and provide operation parameters. By thinking through several use-cases, choices of descriptive parameters, their distribution of values and severity of effect of failure can be outlined. Usually several relevant use-cases can be combined into one enveloping mission profile thus enabling validation with the same plan.

Analyze Use-Distribution – Often EEM/Component stress is significantly higher when operated close to the design limits (e.g., max. load). Also there are use-cases that may result in unusually high load cycle numbers (e.g., taxi driver).

Due to this, considering only possible limits/extremes may not be sufficient, additionally a use distribution is necessary. It shall describe the occurrence likelihood of loads with regard to the operation parameter range.

However, in the case that extreme distributions are ruled out from design considerations or test coverage, failures that may result there from these extreme distributions must still be evaluated for safety and customer satisfaction consequences. Furthermore it should be checked by thinking through use cases, if a combination of different loads can occur simultaneously or sequentially. For certain parts or materials these combinations may provoke different failure modes or accelerate others. Therefore a definition of combined loads may be necessary.

Example – Use-Case Brake application

Stop and Go in the city, breaking every 200 m (high number of cycles, low load)

Highway singular power braking from 200 to 80 km/h (low number of cycles, high load)

6.2 Agree Mission Profile for EEM (System Level with Module Level)

First, possible uses must be collected and be evaluated for relevance. An OEM should supply typical vehicle-oriented descriptions for use scenarios and operating conditions.

- Generate environmental mission profile (e.g., complete ZVEI Application Questionnaire [8]).
- Describe electrical/functional loads (e.g., fill in functional requirements in specification).

6.3 Analyze Failure Modes for Reliability of EEM

With knowledge of the planned design of the EEM, the 1st (... nth) Tier suppliers must check the given mission profile (ZVEI Application Questionnaire) and the resulting loads for completeness with regard to failure modes:

- All potential failure modes have to be traced from component level to module up to system level.
- Critical components have to be identified from system down to component level, which in turn can generate need for an additional / different mission profile.

The collected information on source/effect interaction then should be used for a qualitative analysis to identify parameters of the mission profile which do affect reliability of the system and rank them by assumed impact. This clarifies the significance of each parameter and helps in choosing an appropriate precision in its specification (e.g., requiring use-studies, measurements, a fine-grained distribution or allowing rough estimation).

6.4 Translate to Components Life Time Requirements

The translation to the component level must contain applicable environmental electrical and mechanical loads of the EEM design, especially power losses and active pulse loadings. The loads have to be analyzed for each critical component. The Steps are similar to 6.1.

Step 1: Collect possible operating modes (active, stand-by, special loads, sleep, power supply interrupted, cyclically reoccurring operation, operating mode changes).
Each relevant functionality must be completely covered.

Step 2: Assign operating modes to the defined vehicle lifetime requirements.

Step 3: Describe related loads for each critical component:

- Temperature (distribution, including power loss)
- Temperature cycling (distribution, including active pulse loading)
- Vibration (of the component in the EEM)
- Humidity in the EEM
- Service (ESD)
- Testing
- Processing Assembly
- Electrical

Result: Basis for mission profiles for critical components

Consider: Misuse, safety requirements, transport, and storage

6.5 Agree on Mission Profile for Components (Module Level with Component Level)

An 'application questionnaire' by the module level supplier shifts the focus to components and technologies intended for implementation and their critical conditions. The Module level supplier provides typical component oriented descriptions for environmental and operating conditions.

- Generate the electrical/mechanical loads as a function of the environmental condition.
- Discuss mission profiles for all critical components with suppliers.

6.6 Analyze Failure Modes for Reliability of Component

All potential failure modes have to be traced from component level to module up to system level. Critical loads have to be identified at the component level.

Result: Sensitivity of system availability to parameters of mission profiles is evaluated, which gives indications on parameter significance and need for dimensioning precision.

6.7 Verify Mission Profile at Component Level in EEM (Module Level to Component Level)

Assumptions used in choosing mission profiles should be verified by measurements in the actual application as the EEM becomes available (e.g., temperatures in EEM package areas, temperatures of component in EEMs, load distributions, software driving behavior).

Deviations can be assessed using results from analyzing failure modes for reliability of components. In case of significant deviation there may arise the need for additional testing or even changes in construction.

6.8 Verify Mission Profile at EEM level in Vehicle (Module level and System Level)

A similar procedure to 6.7, but in vehicle.

6.9 Verify Mission Profile at System Level

A similar procedure to 6.7, but with emphasis on distributed or combined functionalities of EEM / sensors in systems.

6.10 Stress Factors and Loads for EEMs / Mechatronics

Stress Factors and loads during vehicle service life include environmental and functional loads as illustrated in Figure 11 and detailed in 6.12 and 6.13.

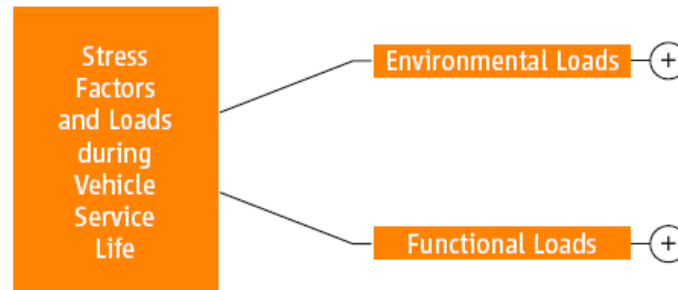


FIGURE 11 - STRESS FACTORS AND LOADS DURING SERVICE LIFE OVERVIEW

6.11 Vehicle Service Life

Service Life of the vehicle can be for example:

- Expected life time (e.g., 10 years, 15 years)
- Expected mileage (200.000 km to 600.000 km)
- Expected operating hours (4000 h to 12 000 h)

As defined in 6.1 and considering vehicle type (passenger or commercial vehicle).

6.12 Environmental Loads in Vehicle

The EEM reliability can be influenced by the environmental loads as shown in tree analysis of Figure 12. Environmental Loads are external stress factors caused by certain environmental conditions, such as temperature, humidity. Etc.

Environmental loads have to be selected from the tree and/or added when necessary for a specific mounting location. Describe and quantify conditions of the relevant loads.

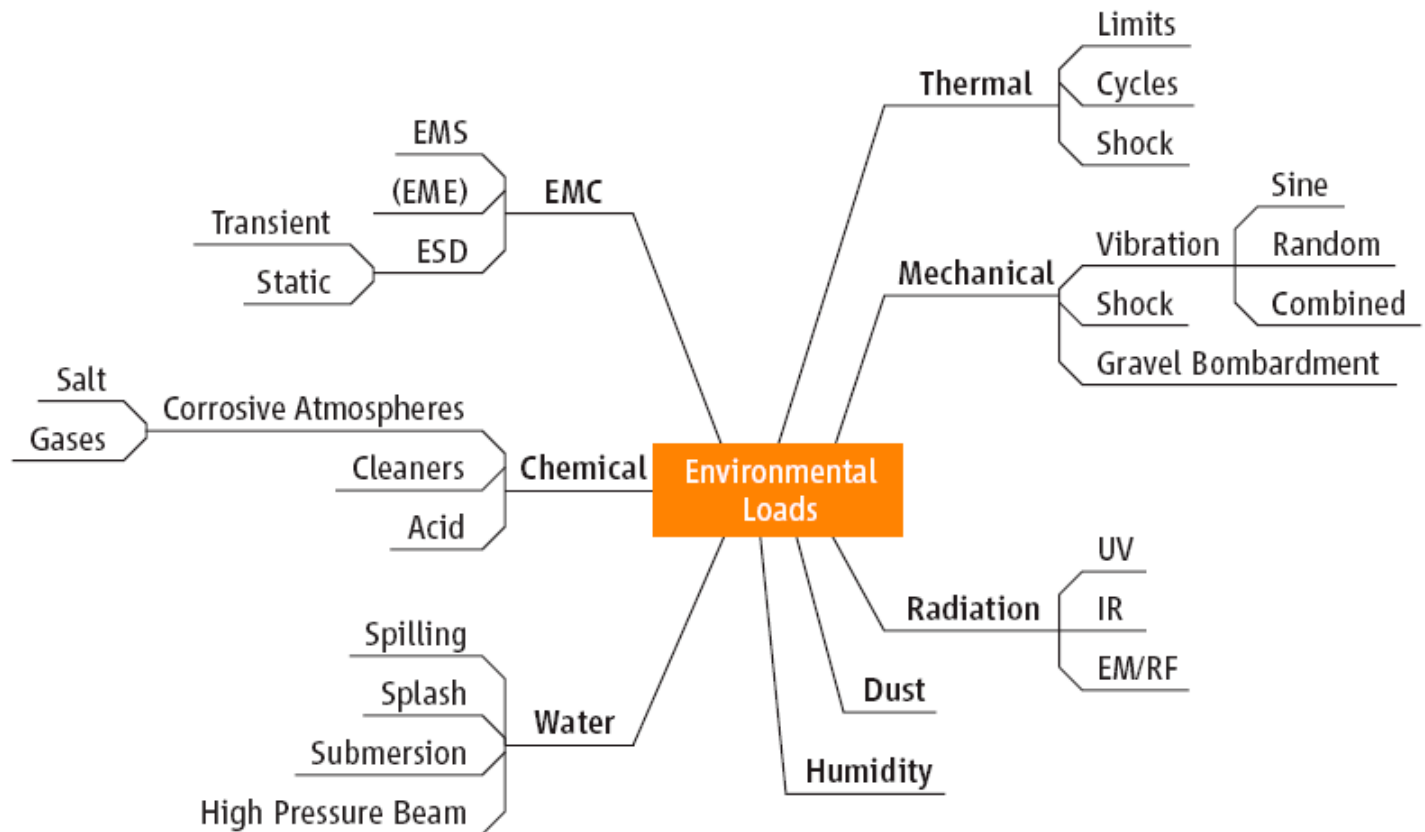


FIGURE 12 - TREE ANALYSIS OF ENVIRONMENTAL LOADS

6.13 Functional Loads in Vehicle

The EEM reliability can be influenced by the functional loads as shown in tree analysis of Figure 13. Functional loads are stress factors caused by EEM operation, usage profiles etc.

Functional Loads for a specific EEM have to be selected from the tree and/or added when necessary. Describe and quantify conditions of the relevant loads.

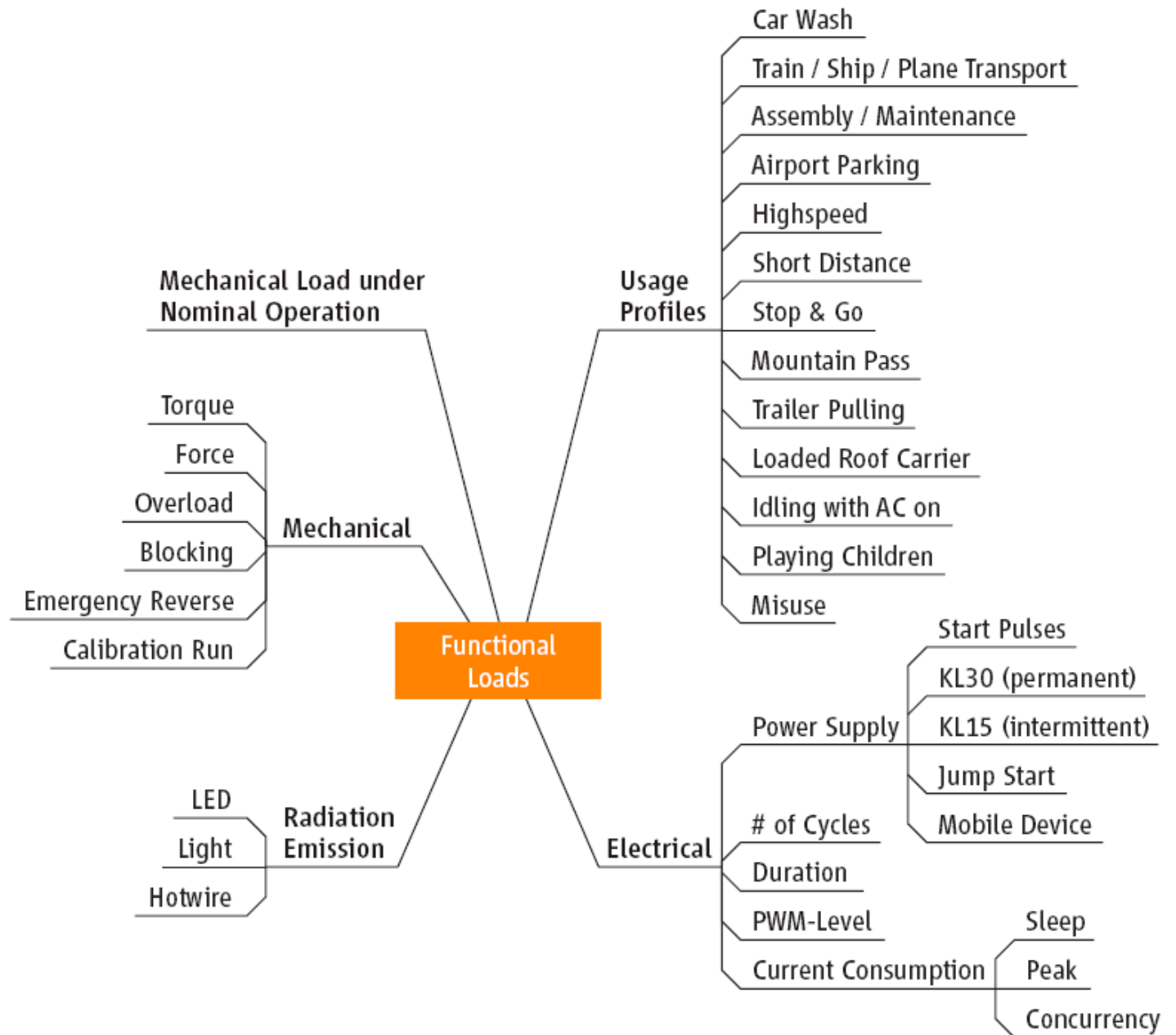


FIGURE 13 - TREE ANALYSIS OF FUNCTIONAL LOADS

6.14 Examples for Mission Profiles / Loads

The Mission Profiles in this section are simplified 'typical' loads for different mounting locations. Note: that these profiles are estimations, which represents typical operational profiles of different drivers in a passenger cars and have to be validated.

However, for several kinds of loads, such as vibration, corrosion, and water intrusion, parameters for lab tests rather than typical values are given.

If the translation of field load to test load is too difficult or the acceleration between field and test conditions (e.g., for some chemical loads) is unknown today, the use of proven standards is encouraged.

See Appendix A.1 and A.2 for Examples of Typical Missions profiles.

7. KNOWLEDGE MATRIX FOR SYSTEMIC FAILURES

7.1 Knowledge Matrix Definition

A Knowledge Matrix is a repository for systematic failures, i.e., failures that are systemic or inherent in the product by design or technology. The Knowledge Matrix is a collection of the lessons learned by the organization using the Robustness Validation process. Extrinsic failures, i.e., failures that are random in nature and predominantly generated by manufacturing processes, are covered in Section 10.

In order to apply and interpret the results of the Robustness Validation process, knowledge of the basic failure mechanisms of the electrical/electronic module is required. The root causes of the failure mechanisms and the effects on the module must be known in order to relate the failure mechanisms to the product's performance and the conditions of use. A Knowledge Matrix can be very useful in identifying potential failure mechanisms and their causes.

To make the development and use of the Knowledge Matrix easier to understand the Knowledge Matrix is divided into several logical groups with the first level being the Component Group. An example of this process is illustrated in Figure 14.

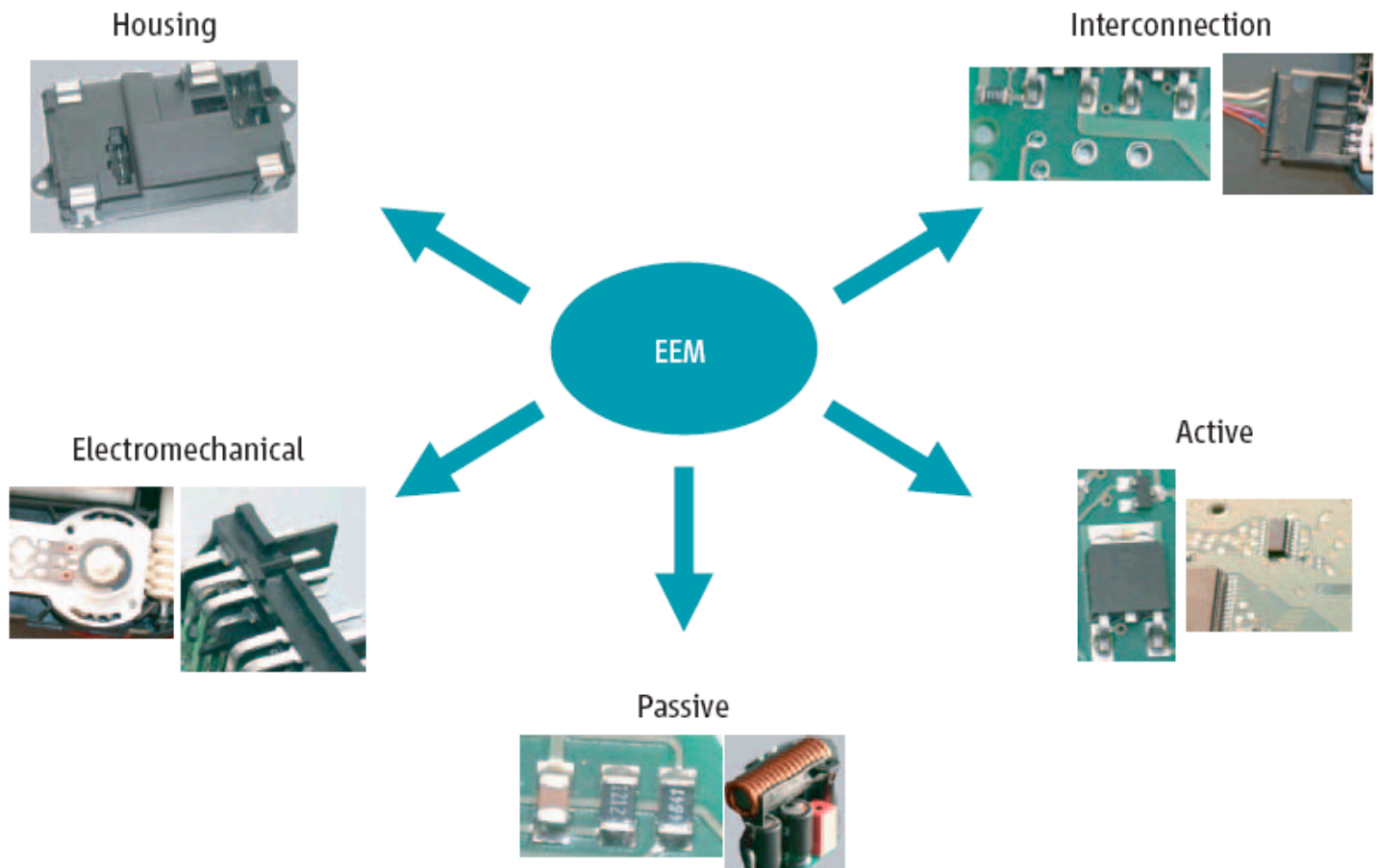


FIGURE 14 - DECOMPOSITION OF AN ELECTRONIC CONTROL UNIT (EEM)

7.2 Knowledge Matrix Structure

The following example Knowledge Matrix shown in Table 4 is defined with the a structure to enable easy navigation of the possible failure modes and causes by taking a module in combination with the intended customer use and breaking it down to the components and technology used to assemble a module.

TABLE 4 - KNOWLEDGE MATRIX STRUCTURE

Field No	Field/Column Name	Field/Column Required	Field/Column Description	Field/Column Content /Example
1a	Main Component Group	Mandatory	Top Level Main Component group	Housing Interconnection Passive Active Electromechanical
1b	Component Sub Group	Mandatory	Components broken down to the next level	Resistor Diode PCB IC Inductor Capacitor Crystal Etc.
2	Product Life Phase	Mandatory	The Product life phase that impacts on the Robustness Characteristics	Design/Development Phase Robustness aspects that are determined during the Initial Design & Development phase of a product life. (e.g. wrong material chosen) Manufacturing Phase Robustness aspects that are determined during the serial production phase of a product life (e.g. too high process temperature) OEM Assembly Phase Robustness aspects that are determined during the assembly of the product into the vehicle. (e.g. mounting force too high) Customer Use Phase Robustness aspects that are determined at 0 km & Field (e.g. incorrect specified operation conditions; misuse)
3	Robustness Aspect	Mandatory	The Characteristic that defines the robustness of the product	Cleanliness (e.g. production process), Resistance , Mechanical stability, Material; operational conditions etc.

TABLE 4 - KNOWLEDGE MATRIX STRUCTURE (CONTINUED)

4a	Failure Mode	Mandatory	The effect by which a failure is observed to occur.	EEM-level: incorrect function Component-Level: Open circuit PCB Track
4b	Failure Cause	Mandatory	The specific process, design and/or environmental condition that initiated the failure, and whose removal will eliminate the failure.	i.e. Excessive Current in PCB track
4c	Failure Mechanism	Mandatory	The specific process, by which physical, electrical, chemical and mechanical stresses act on materials to induce a failure.	i.e. Track overheating from excessive current to point of failure.
4d	Failure Type	Mandatory	Systemic or Random	
5	Failure Stressor	Mandatory	The Type of Stress or combination of stress's required to trigger the Failure mechanism	Temperature Cycle + Vibration, Temperature + Humidity + Vibration
6a	Test Methodology	Optional	If available the test methodology to be used to trigger the failure	This field is intended as a reference guide to assist the user in finding an appropriate test methodology and does not constitute a specific test definition. The RV User has the responsibility to understand the failure mechanism and to determine the appropriate test methodology.
6b	Test Reference	Optional	If available the standard reference used to trigger the failure	This field is intended as a reference guide to assist the user in finding an appropriate test methodology and does not constitute a specific test definition. The RV User has the responsibility to understand the failure mechanism and to determine the appropriate test methodology.

7.3 Knowledge Matrix Use

There are two distinct versions of the Knowledge Matrix - the publicly available example version defined in this document and a company-specific version.

The failure data in the publicly available Knowledge Matrix should be considered a starting point and guide for any user of the robustness validation process as it contains only the generic state of current knowledge information.

Users of the Robustness Validation Process should generate their own Knowledge Matrix based on their own specific product types, and their own personal experience and lessons learned. A format and structure similar to the example Knowledge Matrix illustrated here is suggested. The data contained in the sample publicly available knowledge matrix can be used as a guide and a starting point.

There are many ways to use the matrix, and the way to use it depends on what information is already known and what information is needed. The matrix can be used in a reactive manner when there is a failure mode requiring root cause analysis, and an acceleration model. Likewise, the matrix may be used in a proactive preventative manner to identify potential failure modes in a design during the design phase of a product development, particularly as part of an FMEA.

7.3.1 Knowledge Matrix Use in Failure Prevention (Proactive)

As part of the Robustness Validation Process there should be a review of the user's existing matrix against the Mission Profile and product-specific requirements. The user should also be able to demonstrate the completeness of the review during discussions with the customer.

The user should be able to demonstrate lessons learned that are in the Knowledge matrix and are included in the product design, for example a design review report.

One of the outputs of the review might be the FMEA, which includes the lessons learned.

See Appendix A for examples of using the Knowledge matrix.

7.3.2 Knowledge Matrix Use in Failure Analysis (Reactive)

During a failure incident and as part of the user's failure analysis process the Knowledge Matrix can be used to identify the potential root cause of the failure. When a new failure mode and causes are identified during the analysis, processes that are not currently in the user's Knowledge Matrix should be updated to add the new failure mode.

One use of the matrix is when a failure mode has been observed and there is a need to identify the potential failure causes and/or stress factors (stressors). This may be done as follows:

Step 1 – Filter on the component group (column 1a) and component sub group (column 1b) involved.

Step 2 – Find the potential Failure modes in Column 4a.

Step 3 – Find the potential failure cause in column 4b.

NOTE: It is possible that the specific failure cause does not exist in the matrix. Therefore a new entry would be required to describe the failure.

Step 4 – Find the failure mechanism in column 4c.

Step 5 – Review the potential stressors in column 4d.

The list of potential failure modes, causes and stressors may then be used to plan an investigation to confirm which one is the correct one for the particular failure.

See Appendix A for Examples of using the Knowledge Matrix.

7.4 Knowledge Matrix Change Control

The users Knowledge matrix must be a controlled document within the users organization subject to change control and regularly updated with lessons learned from each product life cycle.

7.5 Lessons Learned

The Knowledge Matrix is intended to be the main repository for all lessons learned within the organization so users of RV must have in place a process to collect and review lessons learned from their RV activities and update their own Knowledge matrix from all sources of experience with EEM failures.

7.6 Knowledge Matrix Availability

The example Knowledge matrix is freely available from the SAE/ZVEI website and will be updated on a regular basis by a team of experts.

Suggestions to update or modify the example Knowledge Matrix are actively encouraged and such suggestions should be sent to CustomerService@sae.org.

The users' company specific version of the knowledge matrix should be available for review by the customer, but is not required to be given to the Customer.

8. ANALYSIS, MODELING AND SIMULATION (AMS)

8.1 Introduction to the Use of Analysis, Modeling and Simulation

Analysis is the process of studying the nature or operation of an issue, item or substance by sorting out and investigating the component parts so that the relationships of how something is made and why it functions the way it does can be understood. Engineering analysis can focus on either of two objectives: 1) Learning how and why things work or do not work in order to resolve an issue or 2) Using the knowledge and lessons learned from past endeavors to predict how new designs or processes will perform. Many different types of analysis techniques have been developed to deal with different technologies, materials and issues, and which are essentially either a physical, intellectual or mathematical and sometimes statistical process.

It is not the intent of this handbook to go into detail regarding the many established and emerging analysis techniques available today. Engineers not familiar with such techniques are encouraged to seek out, study and apply them as needed. Internationally accepted standards and guides which provide an overview of proven techniques are readily available [10, 11, 12]. Detailed information, whether basic or state-of-the-art, on specific techniques, such as Sneak Circuit Analysis [13], FMEA and Fault Tree Analysis [14, 15, 16], and Worst Case Circuit Design and Analysis [17, 18, 19, 20] are also easily obtained through SAE International, Inc., national and international standards organizations, professional societies and journals, and bookstores.

Modeling is the creation of a representation of a process, device or system, used in predictive analysis to evaluate the behavior of new systems. Engineering models are typically math based and are often incorporated into computer programs. The models can be either empirical (i.e., based on observation of a results or an outcome) or phenomenal (i.e., a model of the actual phenomenon and processes that produce the outcome). Phenomenal models are typically more detailed and therefore more complicated to use. However this results in greater accuracy and makes them more applicable to a wider range of circumstances than empirical models. Care must be applied when using empirical models since they are typically accurate only under a limit range of conditions. These models give birth to the term cook book equations and the common modeler saying that "all models are wrong, however some models are useful if you know how and when to use them". Therefore it is essential that modeling activities first require diligent development and validation of the foundation mode that includes understanding the limitations and ranges of linearity or nonlinearity of the model and how accurately it represents real world conditions.

Simulation refers to the use of one system or media to represent the behavior or characteristics of a real world system. Sophisticated engineering computer programs are increasingly required and used to bring life to engineering models by simulating complex events and functions. True simulations attempt to emulate the sequence of deterministic (i.e., cause and effect) internal processes that produce a result by using phenomenal models and not merely predict an outcome or results of an item being simulated. Simulations may also provide a visual representation of the fundamental processes and the results in addition to mathematical and graphical results.

Advancements in computing power, simulation software and modeling algorithms are fuelling rapid progress in automotive **Analysis, Modeling and Simulation (AMS)** methods especially when performed in an integrated Computer Aided Design (CAD), and Computer Aided Engineering (CAE) environment. The skilled, up-front use of CAE analysis improves the optimization of product performance, quality and reliability while reducing the overall time and costs of design, development and validation.

In a modeling and simulation environment, design and analytical Development and Validation (D&V) become essentially one task. The role of AMS in a product development process starts as virtual prototyping tasks for evaluating and (when needed) optimizing features and functions of a new design. The design evolves under this analyze and revise process until the designer and analyst (or designer/analyst) develops and demonstrates a design that can operate in accordance with the requirements and under expected variation and noise factors. The virtual D&V process is completed when it can be demonstrated analytically with accepted and proven models and validation assumptions that the virtual (paper or CAD) design's theoretical capabilities are acceptable to the project's requirements.

Sometimes, the opposite may be proven, i.e., that a specific design approach is not capable of meeting requirements. In this case an organization may save a significant amount of time and resources by not pursuing a design path that is incapable of acceptable performance. However, generally the objective of AMS activities is to grow the capabilities of the design to the point where it is found to be theoretically capable of consistently achieving its requirements and goals while operating in its intended environment. The pre-optimized design can then advance to physical build and test evaluations. The benefits of AMS virtual development and validation processes are:

- Performance, durability and reliability robustness issues can be developed and optimized without the time and cost of physically building and testing prototype parts.
- Designs move in to physical testing pre-optimized by analysis activities that have already screened out many defects and discrepancies.
- Physical testing can be smoother and faster without as many interruptions for fault detection, root cause trouble shooting and corrective action events.
- Physical testing can be optimized. [4]
- Physical testing then does not need to be totally comprehensive, it can be reduced to a series of spot checks of critical features and refocused to criteria that cannot be evaluated by analysis.

This rapid combined virtual D&V approach is possible in an integrated CAD-CAE environment because the results of an evaluation can be used to immediately make informed, feedback guided revisions of design features as needed. The virtually revised design can then be rapidly re-evaluated in the AMS environment in order to gauge the degree of improvement until acceptable performance is achieved. The analyst then moves on to the next design criteria until all aspects of the design have achieved the desired level of robust performance, durability and reliability.

In the physical world the pace of D&V activities are limited by the time and cost required to physically Design, Build, Test and Fix (DBTF) successive generations of prototype parts. These real world limitations require the creation and coordination of a series of sophisticated, complete build and test cycles that must cover all aspects of the new design in each round of testing. Formal product validation is intended to be the final physical test series in this process. However, rarely does physical testing identify and resolve all discrepancies to result in a final robust product. Usually the rounds of physical DBTF activities conclude with the design being deemed "good enough" to advance into production launch activities where reliability and capability growth continues via warranty events and customer dissatisfaction feedback.

8.1.1 AMS Scope

This section provides an introduction to Computer Aided Engineering (CAE) Analysis, Modeling and Simulation evaluations and how they can be applied to evaluate, optimize and ensure robustness of Automotive Electrical/ Electronic (E/E) devices and defines recommended practices on how to integrate AMS procedures into development and validation procedures for E/E devices but it does not define the detailed requirements of each modeling or simulation method which are covered in SAE J2820.

This section is a summary of general-purpose math based evaluation techniques and CAE analysis tools that can be applied to calculate a wide range of product characteristics and capabilities common to many E/E devices. These methods can be applied individually or in groups during any product phase to:

1. Calculate capabilities of early design concepts.
2. Perform robustness optimization and virtual validation of a CAD or paper design of a product.
3. Perform test planning, test optimization and extrapolation of test results to field conditions.
4. Investigate and resolve discrepancies.

Four categories of proven AMS tools and modeling methods are defined that can be applied to assess a wide range of E/E product requirements during early product development. These are:

1. E/E Circuit and systems analysis for evaluating performance, power issues and how performance is affected by variation.
2. Electromagnetic Compatibility (EMC) and signal integrity analysis.
3. Stress analysis for determining thermal and mechanical loads, peak stresses, stress distribution and stress transmission paths and evaluating if the design is strong enough to support the stresses.
4. Physics of Failure based failure mechanism susceptibility analysis for evaluating the durability and reliability capabilities of a design.

When properly applied AMS methods are capable of determining the theoretical performance and durability of a proposed new design. However, modeling and simulation methods are unable to predict what kind of manufacturing errors or variation issues could be inflicted on a design and what their outcome might be.

8.1.2 AMS Mission

It is the mission of this section to foster the development and use of efficiency enhancing E/E AMS CAE techniques by providing a reference resource of Models, CAE tools, methods and a structure for integrating CAE techniques into E/E product development processes and A/D/V plans.

It is the responsibility of the product engineer or team to determine which AMS objectives and procedures are relevant for a specific device, technology or application and how to interpret the results and define application specific acceptance (pass/fail) criteria when appropriate. However, general guidelines for interpretation and acceptance criteria are provided.

It is up to product teams to balance the selection of analysis objectives and tasks for mitigating design risk factors against constraints factors such as: availability of CAE resources, component models, expertise of analysts, manpower, and budget etc.

The techniques defined in this document are not all-inclusive due to the dynamic rate of development of new AMS techniques and CAE tools; teams are encouraged to consider the use of other applicable analytical methods as they become available.