SAE International

SURFACE VEHICLE RECOMMENDED PRACTICE

J1211 NOV2012

Issued 1978-06
Revised 2012-11

Superseding J1211 APR2009

(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 of 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 ºC to +85 ºC); 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., -40ºC and +85ºC) 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.