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PROMPT

Premature Obsolescence Multi-Stakeholder Product Testing Program

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On reliability testing of electronics from a product test perspective of consumer goods

A Guideline and recommendation to reliability testing of electrical and electronic equipment

Content

1 Introduction and Scope

Electrical and electronic equipment (EEE) is considered to be one of the fastest growing waste streams. "In 2019, approximately 53.6 million metric tons (Mt) of e-waste (excluding PV panels) was generated, or 7.3 kg per capita. It is estimated that the amount of e-waste generated will exceed 74 million tons in 2030. Thus, the global quantity of e-waste is increasing at an alarming rate of almost 2 million tons per year."[1] This increase of waste is problematic because these devices involve numerous different materials, components and assemblies, some of which have been generated with a high input of resources and energy. These expenses cannot be fully recovered by recycling. Therefore, it is necessary to keep precious resources within the economy and to reduce waste generation. A promising approach is the extension of the useful lifetime of EEE and avoiding premature obsolescence.

In order to get closer to this target and to be able to evaluate methods to increase lifetime, it is vital to establish criteria that enable a quantification. Based on these consumers could be enabled to make an informed choice between products. The PROMPT project consortium identified component reliability, product design features concerning repair, reuse as well as user and market-related factors as the most critical categories to be analyzed in order to develop a testing program.

This report focusses on the reliability and durability aspect only, where we basically follow definitions given in the Standard EN 45552:2020 on "General method for the assessment of the durability of energy-related products". Moreover, this report focusses on the considerations to be done in the set-up of a test program from the perspective of a consumer organization or market surveillance authority. In this situation, reliability is to be assessed when the product is placed on the market. Since different information is available to consumer organizations or market surveillance authorities compared to manufacturers and product developers, the approach to test for reliability will differ, as exemplified within this report.

The PROMPT project focused its analysis on four product groups. On the one hand smart phones and smart TVs that belong to consumer electronics and on the other hand white goods like washing machines and vacuum cleaners were investigated in detail. This approach enables the development of specific tests as well as capturing the fundamental differences between the groups.

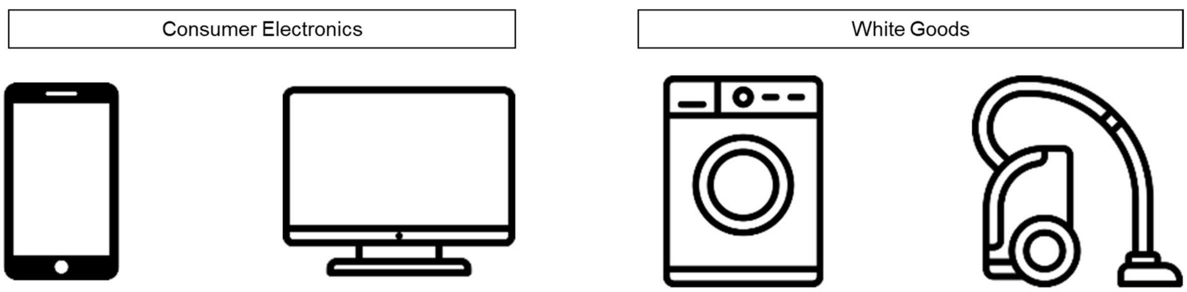

Figure 1: Indication of product groups analyzed in the PROMPT project

During this development some essential lessons learned were identified and are summarized in this report. The resulting recommendations are formulated as a generalization, which can be employed during test development for other product groups.

[1] V. Forti, C. Baldé, R. Kuehrand and G. Bel, "The Global E-waste Monitor 2020", United Nations University (UNU)/United Nations Institute for Training and Research (UNITAR), International Telecommunication Union (ITU) & International Solid Waste Association (ISWA), Bonn/Geneva/Rotterdam, 2020.

2 Summary of Results

2.1 Priority Parts, Failure Modes and Mechanisms

The starting point for the development of a reliability test is the identification of dominant failure modes, which are limiting the lifetime of the products within the product group.

Typically, the failure descriptions of main public sources are limited to the parts which are failing. Therefore, the focus on so called priority parts has been identified as a method that helps to prioritize the test development. The procedure to define product specific priority parts is based on the standard EN 45554:2020, yet limited to two criteria: failure likelihood and functional relevance of a part/component. Components with a high functional relevance and high failure likelihood are defined as priority parts. Components with a high functional relevance and medium failure likelihood can be included in the priority part list after a detailed analysis. All other components are not considered as priority parts. The assessment of failure likelihood and functional relevance is based on available data (surveys, repair statistics, scientific articles, eco design documents and similar).

Table 1: Evaluation scheme for evaluating priority parts

Relevance Value		Failure Likelihood		
		Low	Medium	High
Functional Relevance	Low	0	0	0
	Medium	0	1	2
	High	0	3	4

Display assembly	4
Battery	4
Charging connector	3
Main board	2
Microphone	2
Speakers	2
External power supply (charger)	2
Front-facing camera	1
Rear-facing camera	1
Other connectors (headset)	1

Main board	4
Display assembly	4
TCon board (attached to display)	4
LED board / backlighting	4
Internal power supply / power board (incl. inverter board)	4
Speakers	1
Connectors to connect external equipment (cable, antenna, USB, DVD and Blue-Ray)	1

Door Seal	4
Shock Absorbers	4
Pumps	4
Heater	4
Door Lock	3
Drum Bearings*	3
Electronics*	3
Hoses	3
Tub Assembly	3
Door	3

Motor	4
Battery (if available)	4
Filter (dust bag, exhaust filter, etc.)	4
Floor nozzle	4
Cord reel	3
Suction hose	3
Handle	3
Casing (dust compartment cover, etc.)	3
Wheels	1

Figure 2: Overview of an assessment for priority parts in the investigated product groups

Within WP 3 of the project, a special focus has been given to the following parts, because they play a special role within the product groups:

- Mechanical parts in white goods
- Electronics
- Batteries

Batteries are gaining importance in many kinds of electric and electronic equipment and therefore there is a trend of increasing relevance and limited knowledge about suitable tests. Electronics represent priority parts in many product groups. However from the perspective of consumer organizations and market surveillance there are no specific tests used in today's product testing. Mechanical parts are vital especially for washing machines, where current endurance tests are time and cost intensive. Therefore faster evaluation approaches are needed.

In the next step possible failure modes and mechanisms have been analyzed and discussed for the specific parts and product groups. The results were compared to existing test standards.

2.2 Electronics

Regarding reliability of microelectronics, well established methodologies and standards exist which are being used within the industrial supply chain. In this respect, reliability is the result of a development process. However, from the consumer and market authority perspective there is no existing test approach that gives a clear indication on the potential lifetime and quality of electronics within electric products. Different first labels regarding durability and reparability exist (i.e. LONGTIME®, ONR 192102:2014, HTV-Life® …), yet only some have a specific focus on the quality of electronics and printed circuit boards, while clear test criteria are not yet published. Therefore, in a first step different existing options were evaluated regarding the question: How can the reliability of an electronic control unit (ECU) be tested from an end user's perspective? This discussion forms the basis for the next development step. Basically, three different approaches are available, which are summarized in Table 2 with their respective advantages and disadvantages.

Visual quality inspections are used by consumer organisations for evaluation of most product groups. These can include assessment of the general appearance of the product, the robustness of mechanical construction, screen image quality and others. In the case of ECUs, visual quality inspection necessitates disassembly of the appliance to access the ECU. This may constitute an obstacle if the appliance is not optimized for disassembly and repair, e. g. employs plastic clips/tabs or glue instead of screws for assembly.

Visual quality inspection of printed circuit board assemblies (PCBAs) can include inspection and evaluation of manufacturing quality and choice of components as well as design aspects. Examples for manufacturing quality are the evaluation of solder joint quality, existence and quality of a conformal coating. Solder joints can further be inspected for flux residue which may indicate increased corrosion tendency[1].

Evaluation of installed components can include the quality of connectors and cables, voltage and temperature ratings of electrolyte capacitors and possibly of integrated circuits. Evaluation of design aspects verifies that the design of the PCBA is in accordance with general layout guidelines. This includes the sufficient separation of temperature-sensitive components such as electrolytic capacitors from heat sources, e. g. power transistors to prevent premature degradation of the former. Other aspects are evaluation whether distances between adjacent traces are sufficient to make the PCB resistant to the formation of conductive anodic filament (CAF) or dendrite growth and if the minimum required air and creepage distances between high voltage lines are observed. If possible, the voltage ratings of components and the measured distances should be compared with the voltages present on the PCB during operation.

For PCBs with small structure sizes or components, visual inspection of the PCB can be facilitated utilizing magnifying glasses or microscopes. Furthermore, non-destructive analyses of the PCB can be performed using ultrasound, x-ray analyses or computer tomography to enable examination of inner PCB layers or PCB-to-component interfaces. In case the PCB is accessible during operation, operating voltages may be measured. Temperature measurements can be obtained employing infrared cameras to compare to the maximum operating temperatures of the components. Additionally, areas susceptible to thermal cycling can be identified. If the PCB is inaccessible during operation, temperature measurements may be conducted by fastening thermocouples to sensitive areas of the PCB.

Subcomponent tests involve disassembly of the appliance to access and remove the ECU which constitutes a potential disadvantage in case the appliance is not optimized for disassembly and repair. The extracted ECU can then be subjected to reliability or environmental tests. Various environmental tests for electronics are harmonized in the IEC 60068 standard, with further specialisation for semiconductor devices in the IEC 60747. These cover climatic tests as well as dynamic tests. Climatic tests consist of temperature and humidity tests, e. g. cyclic

[1] M. Jellesen, D. Minzari, U. Rathinavelu, P. Møller and R. Ambat, "Corrosion failure due to flux residues in an electronic add-on device", in *Engineering Failure Analysis*, no. 17, pp. 1263-1272, 2010.

temperature change, constant high or low temperature or high humidity. Dynamic tests consist of vibration or shock tests. Combined climatic and dynamic tests are also covered, e. g static high temperature, high humidity and high pressure tests known as pressure cooker tests or cyclic temperature change and combined vibration tests.

Accelerated lifetime tests are usually conducted until the device under test meets a specified failure criterion. The tests are designed so that the stress applied during the test is similar to but significantly greater than use stress. After conduction of the test, the acceleration factor can be calculated from the ratio of test stress and use stress. This acceleration factor can then be used to calculate the lifetime of the device under use conditions.

An alternative for subcomponent tests is to isolate a specific component. Test boards have then to be manufactured that allow testing of this specific component.

System tests subject the complete appliance to specific tests scenarios corresponding to normal or accelerated use. The extent of these tests often is designed to specifically simulate the loads occurring during and amounting to the whole product lifetime. In this scenario, the ECU is subjected to various loads. Failures of the ECU are observed if they result in failure or fault of the complete system. System tests are routinely employed by consumer organisations for tests of domestic appliances such as vacuum cleaners or washing machines[1]. Also analyses exist, which intend to accelerate the related test procedures[2].

Table 2: Advantages and disadvantages of different test principles

	Visual Quality/Design Inspection	**Subcomponent Tests**	**System Tests**
Advantages	• Low cost and testing time • Identification of systematic issues	• Selective stimulation of specified failure modes • Acceleration possible • Statistical relevant number of samples testable	• Common test conditions for a product group • Initiation of different failure modes • Possibility to communicate results to end users
Disadvantages	• Limited to generally known design/process flaws • No technology variation can be considered	• Specific test equipment needed • Test conditions with respect to product specific mission profile	• Complexity to simulate a realistic use environment • Variations in use profile difficult to cover. • No acceleration possible • No statistical test

During the project, the approaches were ranked regarding failure mechanism, probability of the mechanism, detection probability and feasibility. Finally, a combination of subcomponent test and system test was proposed in order to combine the advantages of both approaches. After a functional verification the electronic control unit (ECU) is removed from the product and tested in a sequential test, which enables accelerated ageing within a load typical for the use environment.

[1] Stiftung Warentest, “Waschmaschinen im Test,” [online]. Available: https://www.test.de/Waschmaschinen-im-Test-4296800-4296814/. [Accessed 29 4 2022].
[2] R. Stamminger, P. Tecchio, F. Ardente, F. Mathieux and P. Niestrath, "Towards a durability test for washing-machines", in *Resources, Conservation and Recycling*, vol. 131, pp. 206-215, 2018, doi:10.1016/j.resconrec.2017.11.014.

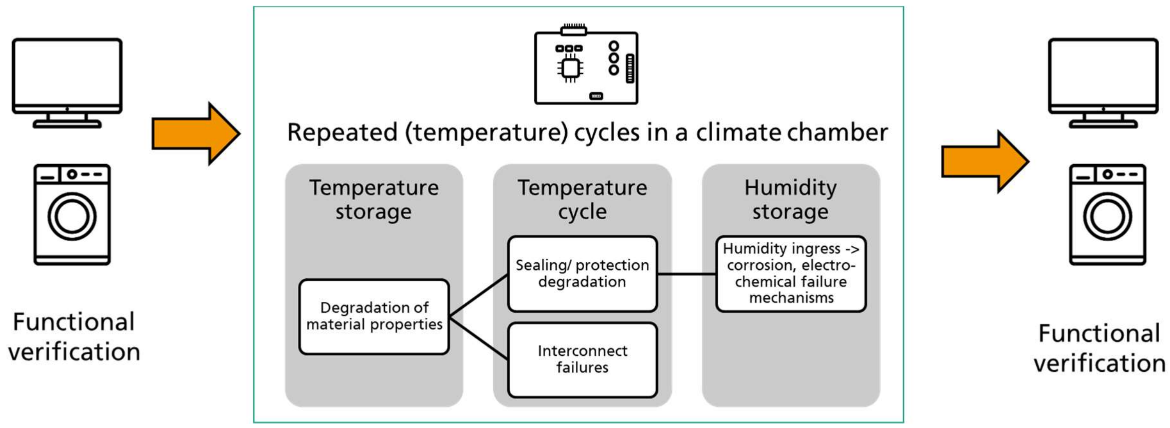

Figure 3: Developed concept for accelerated testing of electronics control units in a product level test environment

The approach is based on a theoretical analysis of mission profiles and accelerated tests to formulate a minimum requirement for reliability. The methodology is applicable to different product groups and involves the separate accelerated loading of electronic modules.

- Specific test conditions have been derived for electronics in washing machines and televisions.
- Main environmental conditions are covered: Temperature, Humidity, Temperature Cycling
- A sequential load has been proposed to cover different environmental loads with a minimum number of samples. So, the methodology is applicable to organizations with limited access to samples (consumer organizations, market surveillance, …)

Within the project the approach is implemented in the validation program for washing machines.

2.3 Batteries

A major issue in high-end digital consumer electronics is the degradation and lifetime of lithium ion batteries, as they often limit the lifetime of the complete product. For example, many users (40%) see a defective battery as a reason for replacement of their device[1]. Current test standards only address testing the performance data (nominal capacity, internal resistance and power capability), the safety (including abuse conditions) and transport. There is no generalized approach allowing a qualified lifetime prediction of batteries. Typically, batteries are cycled in accordance to the load profile of the product until a benchmark (80% of nominal capacity) is reached. Therefore, the PROMPT project dedicated its activities in identifying new methods for battery testing.

2.3.1 Secondary battery assessment and aging model

A generalized lifetime test approach for lithium-ion batteries in consumer products that minimizes the test time and gives a guideline on how the test confidence is linked to the effort of the test procedure would be desirable. Battery aging models are also to be considered for that approach.

While a general test can be conducted to compare the quality of batteries from different vendors, the battery degradation depends very much on the use conditions. Hence, a better knowledge of the influence of environmental and use conditions as well as the battery management on the degradation of rechargeable batteries is crucial. Therefore aging models were extended and analyzed, that include the main characteristic use parameters.

State of the art on lithium-ion battery ageing and modelling was analyzed. Two sets of experiments for evaluation of ageing and extraction of model parameters have been executed (small batteries and mobile phone batteries):

[1] H. Wieser and N. Tröger, "Die Nutzungsdauer und Obsoleszenz von Gebrauchsgütern im Zeitalter der Beschleunigung – Eine empirische Untersuchung in österreichischen Haushalten", Vienna, 2015.

- Same ageing behavior of small and large batteries, yet significant differences in ageing parameters
- Fast charging definitively leads to higher cycle degradation but high temperature and voltage are also crucial. Small variations of charging current can have a crucial effect on cycle number.
- Increase of internal resistance results accordingly
- Long term measurements are required for each new type of battery. Short time testing is sufficient to exclude insufficient products and guaranty minimum quality criteria.
- The battery degradation depends to a high degree and very sensitively on temperature, cell voltage and charging current. Those parameters are not only dependent on the use case but also on the battery management of the device and the applied charging procedure. Thus, the same battery cell will perform differently in different products. Therefore, the longevity of the battery cannot be evaluated outside the electronic product.
- Minimum quality criteria have been defined

2.3.2 Battery test program for application of different loading conditions

Within Working Package 3 of the PROMPT-Project, Stiftung Warentest developed a test program focused only on rechargeable batteries with respect to the consumer perspective. The main innovation implemented in the demonstrated test principle is the fact that the battery lifetime was tested within the product specific battery management of the tested products.

The test program was conducted on lithium-ion battery systems for cordless tools of 18V class. 8 multi-functional battery platforms for cordless tools from different manufacturers were selected. All batteries have a nominal voltage of 18-20 V and a nominal capacity of 2.0-2.5 Ah. Batteries have been tested in two different scenarios which are relevant for their application, a continuous load (leaf blower) and a transient load (cordless screwdriver).

The results of the test were published online at Stiftung Warentest's website test.de[1], as well as in the journal test[2].

The approach can be transferred to other product groups and shows the need to consider realistic use scenarios in test development.

2.4 Mechanical Parts

The aim was to identify potential weak points for the product groups washing machines (WM) and vacuum cleaners (VC), which have their origin in mechanical design (mechanical construction and material selection). To identify these weak points, specific tests need to be designed and/or identified that can detect premature obsolescence on mechanical parts. Based on the product group analysis R.U.S.Z. defined in a first step a feature analysis test approach.

Critical parts causing failures and consumer behavior, which lead to replacement, were identified for WM and VC. Critical parts in average WM causing the most frequent failures were drain pump, drive belt, heating, motor brush, power electronics, shock absorber, inlet hose, drum bearings and entire washing unit. Critical parts in average VC causing failures were suction hose and connection pieces, engine, cable rewinder and casing that secures or covers functionally relevant components, filters, suction pipes, nozzles or hoses.

The knowledge gained from the preliminary work was transferred into the analysis of 10 WM and 6 VC. For the present work, STIWA and TA provided in accordance with R.U.S.Z product samples (10 WM and 6 VC) of different price ranges and expected reliability levels from their testing activity. R.U.S.Z performed a visual inspection,

[1] Stiftung Warentest, "Werkzeugakkus im Test," [online]. Available: https://www.test.de/Werkzeugakkus-im-Test-Diese-System-Akkus-halten-besonders-lange-5665195-0/.
[2] Stiftung Warentest, in *test,* vol. 11/2020, pp. 74-78, 2020.

disassembly, and an assessment of 10 predefined Priority Parts (PP) in WM and 8 predefined PP in VC, as well as the identification of other critical components related to durability and reparability.

The overall method combines disassembly, visual inspection and reassembly and can therefore be used for reliability assessment based on visual inspection of design features as well as for a reparability assessment.

The study showed that distinct design features which could have an effect on the mechanical product reliability become visible in this way. The evaluation examples have been documented and a scoring system was being suggested for the validation part of the project.

2.5 Discussion for Generalization

During the development of product/component level reliability tests for the specific product groups, some basic issues and limitations became visible, which should be considered for the next development steps and transfer to other product groups.

- Reliability testing from the end user perspective remains challenging, because reliability is the result of an engineering development process, which is not visible at the point of sale.
- The developed tests cannot cover all aspects and therefore they are not sufficient to ensure reliability of products. They are rather intended to be a "spot check".
- The possibilities for lifetime limiting failure modes and mechanisms can be numerous. They differ between different product groups, products, use cases and technologies.
- The selection of tests is the result of many different decisions and prioritizations regarding relevant components, failure modes, mechanisms, available standards, feasibility of test approaches and budgetary limitations. In order to structure this prioritization process for a test program, a procedure for general test development is suggested (Chapter 3).
- The reliability of the tested components depends to a large amount on the Mission Profile for which the tests have been defined (Example: Battery Management). For a comparability of tests and reliability estimations these Mission Profiles should be comparable. Therefore, a draft procedure is suggested (Chapter 4).

3 Procedure for General Test Development

A generalized, structured approach to test development is beneficial to develop product level/component level reliability tests for a broad range of consumer goods product groups. The proposed procedure for general test development is presented in Figure 4 and is described in detail in the following.

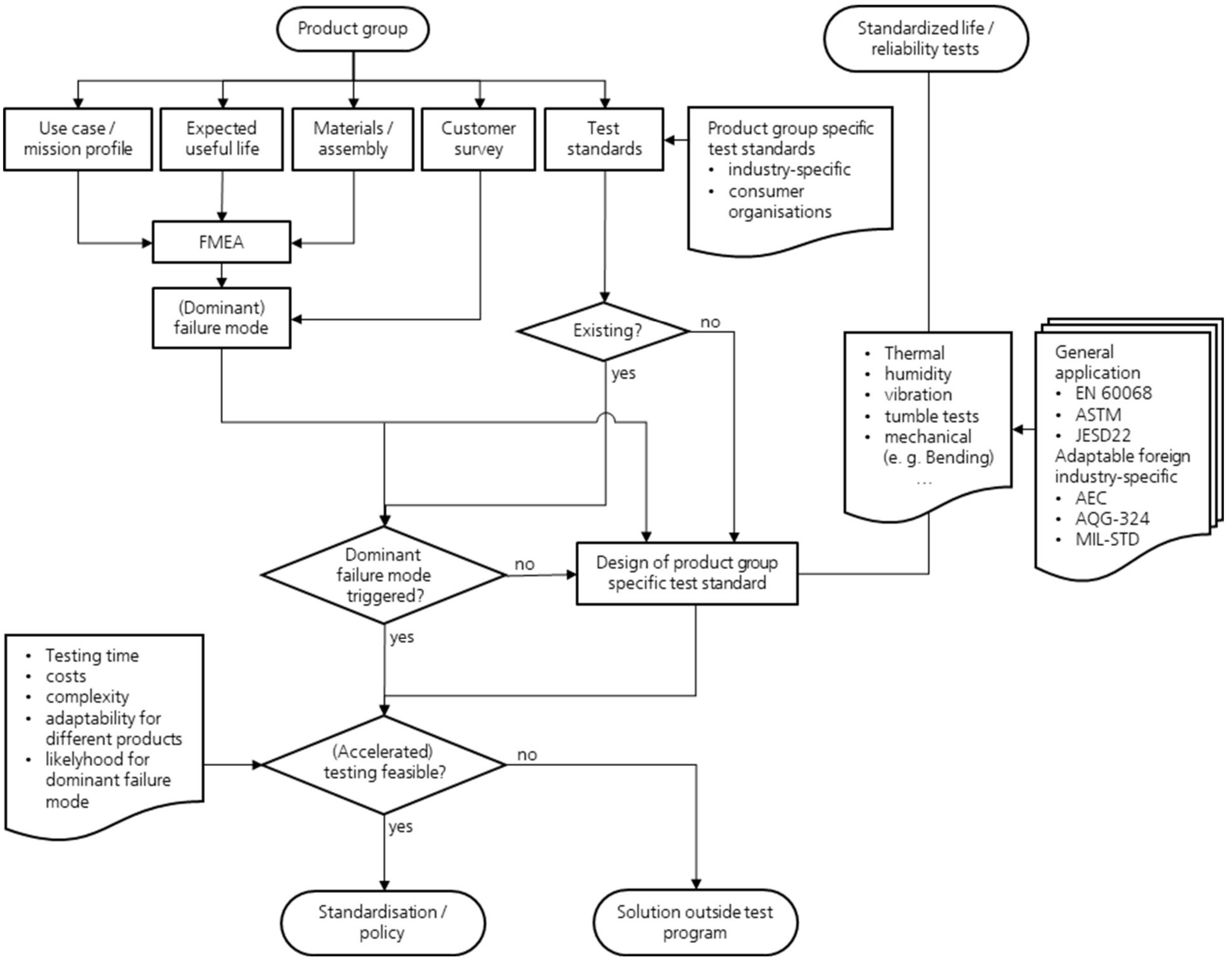

Figure 4: Procedure for general test development

The generalized approach begins with an assessment of possible lifetime limiting or failure inducing characteristics of the **product group**. These characteristics include the definition of the **use case** of the product group and the corresponding **mission profile** which is discussed in chapter 4. Another important factor is the **expected useful life** which can vary significantly across product groups. The expected useful life is influenced by a variety of factors including the product life cycle devised by manufactures and developers, customer expectations, psychological obsolescence and the frequency of technology generations for critical parts, e. g. microprocessors, and their significance on the product life cycle. Finally, the design of the product has to be analyzed, including the **materials** and **assembly** technologies used for manufacturing.

In parallel, **test standards** designed for the product group have to be identified. These can include industry-specific test standards used by manufacturers or developers in the design and qualification phase of the product or test standards implemented by consumer organizations to determine product lifetime and compare product reliabilities of different models belonging to the product group.

The assessed lifetime limiting or failure inducing characteristics can now be used to perform a *failure modes and effects analysis* (**FMEA**) or similar analysis to determine and evaluate possible failure modes and their effect on product reliability and to identify priority parts as explained in chapter 2.1. In the next step, plausible **dominant**

failure mode(s) can be identified. These may include failure modes of priority parts or failure modes resulting from the mutual influence or interdependence of several subcomponents in the complete, assembled system and having an effect at the system level.

Within a product group, a wide variety of materials and manufacturing technologies can be applied resulting in various different failure modes which may not be fully covered by the FMEA with reasonable effort. The additional inclusion of empirical failure data from **consumer surveys** or repair data from manufacturers or workshops is therefore recommended to detect additional probable failure modes and to verify the results of the FMEA.

After the assessment of plausible dominant failure modes and in case of **existing** product group specific test standards, the test standards have to be evaluated against the failure mode(s) and it must be evaluated if the **dominant failure mode** is reliably **triggered** by the test.

If no product group specific test standard exists or the dominant failure mode is not reliably triggered by the existing test standard, a new **product group specific test standard** has to be **designed**. For this purpose, a series **of standardized life** and **reliability tests** such as thermal, humidity, vibration, mechanical and shock tests, e.g. drop or tumble tests, as well as combined tests can be used as base to create a test profile that reliably induces the dominant failure mode. For selection and specification of the tests, a number of standards for general application life and reliability tests can be used, such as EN 60068, ASTM or JESD22. In addition, standards from foreign industries with relatively high requirements regarding qualification and reliability, such as automotive, e.g. AEC standards or the AQG-324, or standards from the aerospace or military industries, e.g. the MIL-STD-810, can be consulted.

When existing or newly designed test standards are available that reliably map the dominant failure mode, an assessment must be made as to whether **(accelerated) testing** is possible and **feasible** per the corresponding test standard. To this end, various influencing and evaluation factors must be considered, such as the time required to perform the test, the costs and complexity required for implementing and performing the test, the number of different samples that can be examined simultaneously, and the probability that the dominant failure mode will occur within the accelerated testing. Also, the possible adaptability of the test for different product groups should be taken into consideration, as this can save costs and effort in the long run, especially for consumer organizations that often test a variety of different products.

If the newly designed or available test facilitates accelerated testing of the respective product group, the procedure for test development was successfully carried out and further steps can be undertaken to transfer the new test into further **standardization** or implement a corresponding **policy**, e. g. for mandatory product testing. If the examined test does not allow feasible (accelerated) testing, the design of an appropriate test standard is not possible with the proposed procedure or the available means and tests. Then a **solution** must be devised **outside** the **test program**.

4 Procedure for General Mission Profile Definition

One of the key points for testing with the goal of results that can be compared is to have a common basis to test for. Often such common basis in form of a mission profile is missing on all levels (consumer, consumer organizations and manufacturers).

4.1 General Procedure for Reliability Assessments

Minimum cost, sufficient performance and demonstrated durability are key criteria that must be met during building product's robustness in order to achieve successful and sustainable commercialization[1].

An application-independent reliability assessment procedure (**Figure 5**[2]) is to be employed in order to determine the component-level and system-level reliability of the product under the given mission profiles and operating conditions. Before analyzing the durability and the lifetime of the components of interest, the input mission profiles need to be translated into the main stressors that lead to the wear-out failure of the components, e.g. temperature, voltage, mechanical stress[3], from which reliability tests can be derived, which in turn must finally be verified and validated.

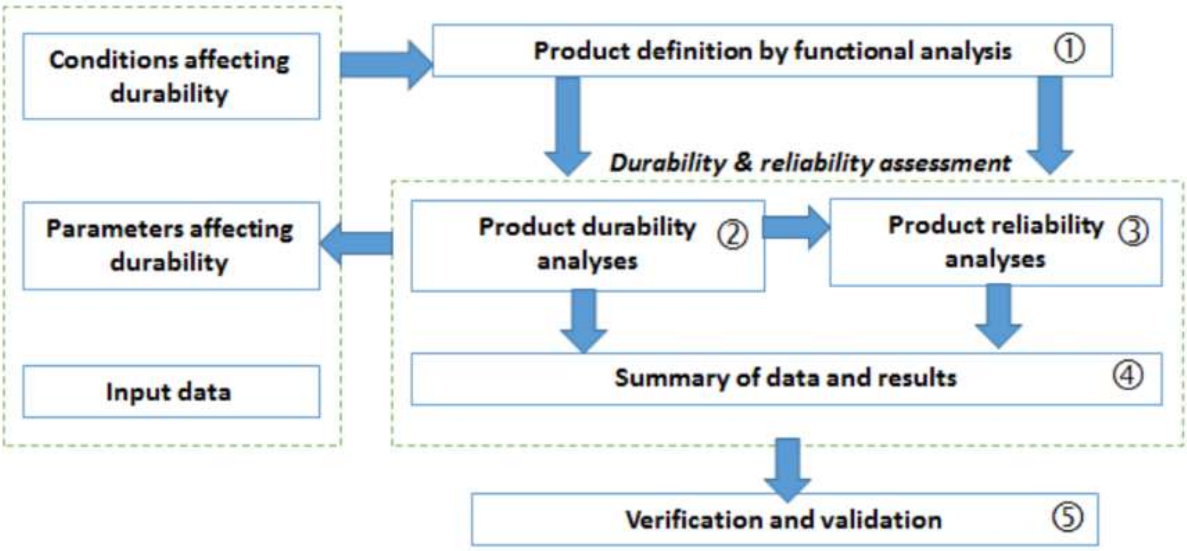

Figure 5: General durability and reliability assessment procedure

4.2 Mission Profile based Reliability Assessment

Mission Profiles (MPs) simply represent all relevant static load conditions and dynamic load profiles that a population of electrical, mechanical, electronic and electro-mechanical components are exposed to during their entire life cycle, which cover the manufacturing, testing, storage, transportation as well as the operational and passive use of a component or product, respectively.

[1] B. T. Carlsson, K. Möller, J.-Ch. Marechal, J.L. Chevalier, M. Köhl, M. Heck, S. Brunold and G. Jorgensen, "General methodology of test procedures for assessment of durability and service life", [online]. Available: https://www.osti.gov/etdeweb/servlets/purl/20675192.

[2] "General method for the assessment of the durability of energy-related products", prEN 45552: 2019

[3] T. Eikenberg, "Automotive Electronics Reliability Testing Starts and Ends with the Mission Profile", Monolithic Power Systems, [online]. Available: https://www.monolithicpower.com/en/automotive-electronics-reliability-testing-starts-and-ends-with-the-mission-profile

MPs will not only provide an effective assessment of the products life expectancy, they can also deliver reliability design information. This is important to aid in manufacturing and thus helping towards reducing costs and maximizing availability through life[1].

The concept of MPs is universally applicable and therefore not restricted to a specific area of use. MPs contain essential information for[2]:

- The specification of target criteria for the development of new manufacturing technologies.
- The evaluation of the general maturity and robustness level of existing manufacturing technologies.
- The evaluation of manufacturing technologies with regard to their special suitability for the manufacturing of reliable and robust components.
- The evaluation of component robustness and reliability.
- The construction, verification and validation during the design and testing phase of components.

The application of MPs is therefore fundamental to technology development, product development, robustness validation and reliability engineering.

Methodologies for creating and classifying mission profiles are extensively described in the publicly funded project *RESCAR 2.0* [3] for the automotive industry but the approach can be applied independently of the field of use.

The basis for a robust design is knowledge of the component's area of application as well as their target lifetime. Environmental influences and the particular boundary conditions in each case must be taken into account, as well as electrical parameters, duration of use and singular events. These conditions can be summarized in mission profiles. However, creating them is anything but trivial. They should represent reality with sufficient accuracy and refer to relevant failure mechanisms as well as their related severity. At the same time, they must not contain uncontrolled amounts of data, as this would make efficient use impossible. The number and level of detail of the recorded parameters must be kept as minimal as possible, yet as extensive as necessary[13].

The most commonly referenced stresses are related to temperature/voltage and thermomechanical stress. Temperature/voltage stress is understood as the main aging effect for integrated circuits (IC) and semiconductors. This aging effect impacts the material properties such that the IC will see a performance degradation over time or spontaneous failure due to overstress of degraded parts. Thermomechanical stress refers to the mechanical forces that occur while a part expands and contracts from temperature variation[4], which leads to failure of parts of the interconnect and packaging technology in most electronic components over time.

In most industries, it is common to estimate the electronics reliability of an application versus their target lifetime, or, in other words, whether the electronics will able to withstand the overall lifetime stress during typical use conditions. To make a reasonable judgment, it is necessary to understand what kind of stresses the electronics will be subjected to during use (field life). Subsequently, this anticipated field life stress must be compared to the stress that all electronic components in the application were originally qualified for. From there, it can be determined if the anticipated field life stress would overstress any device in the application, potentially leading to premature failures[5].

[1] M. Musallam, C. Yin, C. Bailey and M. Johnson, "Mission Profile-Based Reliability Design and Real-Time Life Consumption Estimation in Power Electronics," in *IEEE Transactions on Power Electronics*, vol. 30, no. 5, pp. 2601-2613, May 2015, doi: 10.1109/TPEL.2014.2358555.
[2] http://www.mpfo.org/mpfo-0.7/mpfo_ch_introduction.html (last accessed 20.10.2022)
[3] A. Burger, G. Jerke, S. Straube, D. Hahn, U. Abelein, O. Bringmann and W. Rosenstiel, "Mission Profile gestützter Entwurf von Automobilelektronik", edaWorkshop 14, 2014, 10.13140/2.1.3117.3921.
[4] I. Vernica, H. Wang and F. Blaabjerg, "Impact of Long-Term Mission Profile Sampling Rate on the Reliability Evaluation of Power Electronics in Photovoltaic Applications," 2018 IEEE Energy Conversion Congress and Exposition (ECCE), 2018, pp. 4078-4085, doi: 10.1109/ECCE.2018.8558092.
[5] T. Eikenberg, "Automotive Electronics Reliability Testing Starts and Ends with the Mission Profile", Monolithic Power Systems, [online] https://www.monolithicpower.com/en/automotive-electronics-reliability-testing-starts-and-ends-with-the-mission-profile.

4.2.1 Uncertainties and Limits due to Mission Profile based Reliability Assessments

Due to the complexity, Mission Profiles are limited to the most relevant failure mechanisms that can be translated into simple tests. Furthermore, in order to be able to improve the confidence and accuracy of the MP-based reliability assessment procedure, the underlying assumptions and uncertainties introduced by the mission profile sampling rate need to be considered. Therefore, to address this issue, an uncertainty analysis needs to be performed and the impact on the lifetime prediction outcome needs to be quantitatively analyzed. The uncertainty analysis can be performed by assessing the reliability of the electronic components under the same system operating condition and lifetime model, yet with different mission profile sampling rates[1]. For example in power devices for photovoltaics, the estimated damage of the device (product) can deviate when the mission profile resolution decreases from a few seconds to a few minutes[2]. Therefore, the resolution of the MP must match the loads and their changes during operation.

Furthermore, it must to be taken into account that most studies about MP-based reliability assessments consider a one-year mission profile, where the analysis assumes that the mission profile would be identical in all years of operation. In reality, the mission profile of e. g. photovoltaics can change from year to year due to climatic reasons and randomness of cloud behavior. The effect of the mission profile length (number of distinct years) on the estimated lifetime of electronic components has not been discussed in the literature yet.[3]

Another important point to consider when developing MPs is that there is often a near-infinite number of possible use cases. Potential solutions to this problem vary: In some cases a number of different use cases is described in the MP, in other cases a singular MP is designed to contain the worst possible conditions. All solutions have disadvantages, like an increased effort to validate multiple MPs or possible over engineering. The important point to consider is that any form of MP will most likely not reflect every possibility. Therefore MPs have to be communicated transparently to any involved party. In such cases, MPs can be developed only for a subset of use cases (e.g. covering 80% of users).

4.2.2 Mission Profiles within the scope of PROMPT

As previously described, MPs can be very complex and detailed. From the perspective of consumer organizations or legislative authorities such detailed MPs are impossible to define. The reason scientific literature is mostly concerned with such degree of detail in regards to mission profiles is because usually a specific technology is the focal point of development.

From the perspective of the PROMPT project MPs have to be viewed from the top level, similarly to the approach developed during *RESCAR 2.0*. A car is a complex system composed of countless components and sub-systems. The OEM often defines only requirements on function and reliability and provides basic information in regard to the MP. Design decisions and development are mostly carried out independently in the supply chain. In this scenario the cooperation between OEM and supply chain can of course be deepened if necessary. For the generalized approach in PROMPT, focusing on the top level description of the MP should be sufficient.

This means that MPs for a product group should focus on describing the generally expected use case. This can include specific load cases, if these are known and well established, e.g. number of expected drops, surface and height of drops for smart phones. Otherwise, general descriptions should be included, e. g. number of use cycles within a certain time frame, duration of a use cycle, rough environmental conditions (e.g. inside, outside, air-conditioned environment, etc.). The aspects to be described can vary between product groups. The focus should be on the description of the user behavior with the goal to develop a MP that can be understood by a consumer as well as a manufacturer. Then the manufacturers have a common guideline for product development. Test can be developed for these mission profiles and consumer organizations would be able to do their own tests or

[1] I. Vernica, H. Wang and F. Blaabjerg, "Impact of Long-Term Mission Profile Sampling Rate on the Reliability Evaluation of Power Electronics in Photovoltaic Applications," 2018 IEEE Energy Conversion Congress and Exposition (ECCE), 2018, pp. 4078-4085, doi: 10.1109/ECCE.2018.8558092.
[2] A. Sangwongwanich, D. Zhou, E. Liivik and F. Blaabjerg, "Mission profile resolution impacts on the thermal stress and reliability of power devices in PV inverters", in *Microelectronics Reliability*, vol. 88–90, pp. 1003-1007, 2018, https://doi.org/10.1016/j.microrel.2018.06.094.
[3] A. F. Cupertino, J. M. Lenz, E. M. S. Brito, H. A. Pereira, J. R. Pinheiro and S. I. Seleme, "Impact of the mission profile length on lifetime prediction of PV inverters", in *Microelectronics Reliability*, vol. 100-101, 113427, 2019, https://doi.org/10.1016/j.microrel.2019.113427.

evaluate and compare tests done by manufacturers. Such an MP would also allow consumers a better estimation for an expected reliability when they compare their own use case with the MP the products are tested and developed for.