Towards a Standardized Format for Automotive Mission Profiles

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Abstract

Mission profiles are fundamental to technology development, product robustness validation and reliability engineering in the automotive development process. They contain a simplified, quantitative representation of external and internal load conditions which a component or system is exposed to during its production and operation. One of the main purpose of mission profiles is the exchange of information between different partners along the automotive supply chain, for instance quantitative requirements or qualification results. Clear and unambiguous communication between the development partners is of key importance for developing reliable and robust electronic and electro-mechanical products. However, until today there exists no standardized electronic data format for mission profiles that enables such unambiguous communication along the supply chain. We present currently ongoing efforts to define and specify the XML format MPFO aiming for international standardization.

1 Introduction

A mission profile (MP) is a simplified representation of all relevant static and dynamic load conditions which an electrical, electronic and electro-mechanical component, or population thereof, is exposed to during its entire lifecycle. The term „lifecycle“ includes production, test, storage, transport as well as operative and passive usage of the component. An MP of a component depends on the particular application, as shown in **Table 1**, where two typical MPs are sketched for a consumer and an automotive component, respectively.

Table 1 Comparison of use-conditions for a typical consumer and automotive component.

	Consumer	Automotive
Temperature	0°C to 40°C	-40°C to 165°C
ESD robustness	up to 3kV	up to 15kV
Lifetime	1 to 3 years	10 to 15 years

Such MP data is essential for instance in communicating application conditions of an ECU from OEM down to the suppliers of the ECU and the components thereof. In the opposite direction it is used to communicate details about the qualification process at the component or ECU level.

By nature, MP data comes in a great variety of representations, some examples of which are shown in **Figure 1**. They may include tabulated data, discrete or continuous analytical formulae, multivariate histograms, integral or differential equations, or stochastic expressions. This wide range of mathematical objects is most probably the reason why until this day no electronic data exchange format for MPs has been standardized and adopted by the industry. Yet, with increasing complexity of the products, the need for such a format grows to enable bidirectional, secure, consistent, and semantically unambiguous data exchange between all partners along the automotive value chain. This will only be accomplished if the format is based on a standard that is supported by common CAD and EDA tools within electronic design flows as well as product life cycle management systems (PLM).

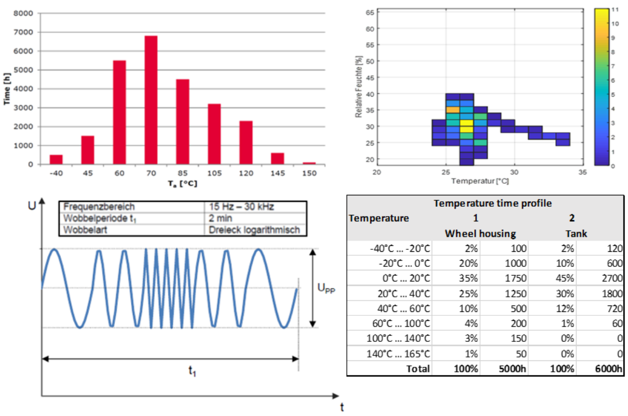

Figure 1 Various typical representations of MP data

In the following we present the work that is underway to define such a file format suitable for international standardization, which has been termed Mission Profile Format (MFPO) [1]. The current development activities of this format are pushed by the German standardization project ELDA-MP [2], where 11 industrial and academic partners from the entire supply chain work together towards such a file format that meets the demands of all players in the value chain.

2 State of the Art

2.1 Previous Work

The design of electrical and electronic assemblies, of semiconductor devices or MEMS devices generally should be oriented towards MPs and also take them into account during validation [3]. ZVEI has specified essential aspects of an effective practice in robustness validation guidelines and procedures [4]. However, the merely conceptual description of these procedures still leads to many individual and manual processes in practice. This statement unfortunately also applies to other qualifications, such as the AEC-Q for components and applications in road vehicles [5].

Environmental conditions and electrical testing for electrical and electronic equipment of road vehicles are defined in the OEM LV 124 [6] and the ISO standard ISO 16750-2 [7] respectively. Several other loads are defined in other ISO 16750 sub-parts, such as mechanical loads (ISO 16750-3), climatic loads (ISO 16750-4) and chemical loads (ISO 16750-5).

The past German and EU-funded projects RESCAR 2.0 [8], RELY [9], autoSWIFT [10], RESIST [11] and TRACE [12] provided over the last years the prerequisites for improving the reliability of components as well as for technology and application evaluation with respect to robustness and applicability in the field of consumer applications as well as for automotive and industrial components.

In [13], the reliability of SRAM cells under the influence of more complex MPs was investigated with periodic activity patterns at different levels (e.g., square pulse, burst mode protocol, day-night rhythm). The use of MPs to evaluate effective stress times and stress levels for semiconductor reliability was successfully demonstrated in [14].

In the RESCAR 2.0 and autoSWIFT projects [8][10], an initial version of a general-purpose MP format was designed. During this early work, the focus was on implementing a proof-of-concept and gathering the basic requirements [15]. As a result, the usefulness and practical application of an electronic MP could successfully be demonstrated and was applied to the design of robust smart power ICs [16].

2.2 Related Electronic File Formats

Different sub-aspects of MPs are already covered by related electronic file formats. However, none of them completely fulfills the necessary requirements for a universal mission profile format.

For example, abstract and comprehensive development requirements can be defined via the Requirements Interchange Format (ReqIF) [17]. However, it cannot be used to describe specific mathematical-physical expressions and complex usage scenarios.

The description of systems, their structure and behavior in abstract application scenarios can be achieved using the System Modeling Language (SysML) [18]. However, SysML cannot describe specific mathematical-physical expressions and detailed load profiles.

An XML-based standard for exchanging results between different programs for data mining and statistical analysis is the Predictive Model Markup Language (PMML) [19]. However, PMML focuses on the exchange of data models.

The Reliability Information Interchange Format (RIIF) [20] can be used for the formalized specification of failure models. It is used for the management of reliability requirements of single components up to complex systems. However, it is not possible to describe sophisticated application scenarios.

The preliminary MP format on which the present work is based was developed as part of the autoSWIFT project [10]. A stand-alone MP format standard of the intended kind should be able to map generic requirements and be able to interact with these and other related file formats.

3 Use Cases for Mission Profiles

3.1 Application of MPs in Verification and Validation

Automotive mega-trends like electrification, functional safety and autonomous driving imply a complexity increase in all automotive semiconductors, like smart power and sensor devices. Besides, these devices have to operate in the harsh electrical environment of automobile systems. Verification, as a major discipline and cost driver in semiconductor development process must assess reliability and robustness of operation under these harsh conditions. While mission profiles in reliability assessment mostly address ageing and lifetime aspects, mission profiles in verification mostly address functional aspects, like load transients, supply transients or similar [21]. A well-known example, which even reached standardization are power supply transients and disturbances, defined in LV124/LV148/ISO16750 [6][7].

A common industry understanding is that only digitalization can help to cope with exploding verification efforts in the future. Digitalization in verification targets the reduction of human intervention in the verification process to the least possible amount or only as instance of supervision. The automated and standardized transport of mission profiles as proposed in this paper forms a crucial part of this process. Other digitalization aspects in verification involve the formalization of functional and performance requirements [22] and the automated assessment of large data sets by means of supervised or unsupervised machine-learning methods [23]. Yet another approach starts at system engineering level and used models (e.g. described in SysML) for verification.

In an idealized future flow, depicted in **Figure 2,** mission profiles and formalized product requirements are combined to automatically generate verification scenarios and assess the verification result in terms of pass-fail decisions or quantified in a suitable robustness metric [24].

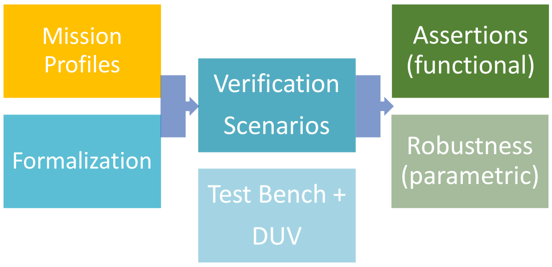

Figure 2 Combination of mission profiles and formalized requirements for automated generation of verification scenarios

Such a flow shall address applicable pre- and post-Si verification domains, which may imply, that a transformation of a mission profile is needed, e.g. when a mission profile on ECU level shall be applied to a sub-component of that ECU. Common needed transformations could be temperature or supply voltage related. A mission profile may exist for the automotive board network, and derived mission profiles may need to be generated for derived supply domains.

Application example: CAN transceiver subjected to power transient mission profiles

In this example, we show how a CAN transceiver as device-under-verification (DUV) is subject to a common power mission profile. Controller-Area-Network (CAN) transceivers form part of the bus infrastructure for micro-controllers in different ECUs to communicate with each other over the CAN bus. Functional requirements of the transceiver are formalized using a Property Specification Language (PSL) [25] to facilitate automated generation of pass-fail information (assertions) based on a formalized specification. The test bench imports the mission profile to automatically iterate over various generated verification scenarios, tests are executed, waveform traces recorded and analyzed using the set of PSL expressions. Sample results are shown in **Figure 3**.

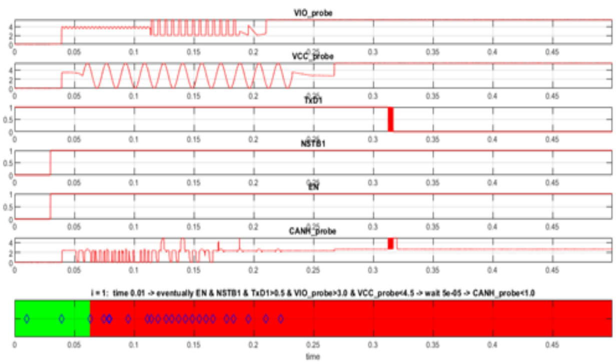

Figure 3 Sample verification results of a transceiver test chip for mission-profile-based supply transients (VIO and VCC) and assertion result (bottom)

In the given case, the DUV is connected to the main board net, therefore the MP can be directly applied. It also contains secondary supplies, which are derived from the board net by means of a voltage regulator. This means that the original MP must be transformed before applying them to the secondary supply as illustrated in **Figure 4**.

In conclusion, the example demonstrates how a combination of mission profiles with formalized (functional) requirements enables a completely automated generation of verification scenarios and the assessment of verification results in the product verification process.

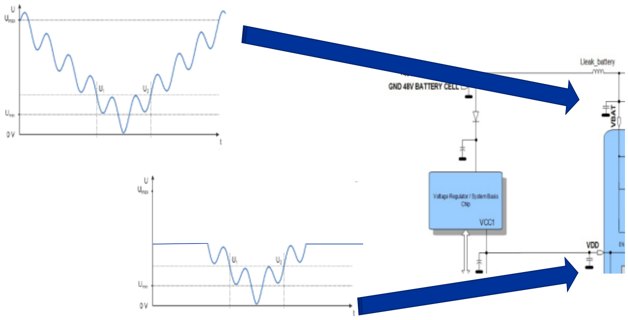

Figure 4 Original (upper left) and derived load for a mission profile (lower left) to be applied as verification scenario to DUV (right)

3.2 Use Cases for Mission Profiles

As the very first step during the format development, much effort has been spent together with the potential end-users in clustering and classification of all possible usage scenarios of the future file format. It is well known from similar standardization activities of the past, that in order to be broadly accepted, the format needs

a) to capture the majority of all use cases, and
b) to be compatible with the relevant industrial tools and application flows.

Since a stable flow integration should be based on a standard, current activities are focusing on the fundamental format development. In order to build upon a solid basis, a systematic list of use cases has been collected during multiple open industry workshops. Exchange within the user community is particularly important since the format developers are usually not identical to the end-users.

As it turns out, MP end-users are to be found along the entire development cycle, i.e.

- Specification and requirement definition,
- Design and implementation,
- Test and qualification.

Various use cases were identified that also involved a large number of different loads and use conditions from different standards, e.g. ISO16750/LV124 [7][6], AEC-Q [5], JEDEC standards, or in-house standards. In order to structure our us cases, we distinguish between primary and supporting use cases. Primary use cases are shown in **Table 2** and relate directly to MP information items describing operational and/or environmental loads.

Table 2 Primary use cases

ID	Description
T-DQA	Technology Development, Qualification and Assessment
C-DQA	Component Development, Qualification and Assessment
C-M	Component Monitoring
M-G	MP Generation
M-S	MP Selection

Supporting use cases as shown in **Table 3** are related to the electronic documents containing MPs including constraints as well as structural information and context.

Table 3 Supporting use cases

ID	Description
MPD-G	MP Document Generation
MPD-U	MP Document Usage
MPD-M	MP Document Management
MPD-V	MP Document Verification and Validation
MPD-T	MP Document Transfer

4 Mission Profile Format

4.1 Fundamental Considerations

Once the usage scenarios are fully defined, the focus of the format development process turns to the format syntax/structure specification. With the use cases in mind, the first decision concerns the fundamental representation, i.e. whether to use a binary or textual form. After due consideration the decision has been made in favor of an XML-based textual format. This decision was governed by the pervasive nature of XML in the engineering domain. Many related standards are XML-based and can potentially be embedded or referenced by MPFO. In addition, XML offers a comprehensive and mature tool support in terms of authoring, syntax validation, transformation, and processing. Finally, XML works best in conjunction with data metamodeling, which will be explained in the following section. On the down side, uncompressed XML files can potentially become very larger in size. However, this does not outweigh the advantages of a human-readable format and may be addressed in the future if necessary.

When using an XML-based format, it is tempting to map the entire format specification to an XML schema definition (XSD) in order to automatically validate document instances. However, as it turns out, XSD is not sufficient to validate all aspects of such a format. Therefore additional technologies are needed such as Schematron and RELAX-NG. Yet, there are certain syntactic or semantic constructs, that additionally require advanced application logic and thus need to be validated by the end-user application. In any case, the final MPFO standard will need to make sure that no ambiguities remain and all end-user applications will be compatible with each other.

The collected use cases contributed a vast amount of requirements towards the format coverage. Some of which have already found their way into the format, others are still under discussion and require additional end-user feedback. Some of the open points include:

- Support for top-down and bottom-up workflows
- Interfacing with external formats
- Traceability over the file's lifecycle
- Clustering of MPs
- Semantic annotation e.g. intent of data items
- Representation of uncertain or stochastic data

The file format development process puts large effort into resolving the above points in order to create the most optimal MP representation format for the end-user.

4.2 Meta Modelling

The core format development starts with the definition of a meta model, which supports the format development directly by formally describing format-specific concepts and relationships thereof. The formal descriptions are abstractions, which enable mapping concepts and relationships to model elements. A model in this context is an instance of a MP expressed in the developed file format. In other words, the meta model defines the language used to describe a MP. Furthermore, the meta model definition supplements format descriptions in standardization documents by providing additional semantics and helps in understanding and analyzing relations between concepts.

We use Ecore to express the format metamodel. Ecore, which is part of the Eclipse Modeling Framework (EMF) [26] is itself based on a subset of the Meta Object Facility (MOF) standard [27]. Conforming to MOF, the format metamodel is therefore compatible with Query/View/Transformation (QVT) standard model transformation languages [28].

From an architectural point of view, the meta model is structured in multiple Ecore models. This distribution is meant to separate specific concerns and enables concurrent development of the meta model to some extent. A single base model defines fundamental MP format meta model concepts and relationships while other models contain definitions of concepts and relationships with a focus on specific aspects. An example for a definition in the base model is the top-level concept of a MP document. The base model contains a definition of the structure of such a document, which includes for example load or port definitions and document properties, e.g., the document description, an identifier or the format version.

Furthermore, aspect-specific models re-use concepts defined in the base model through inheritance.
Finally, the meta model is converted into the final XML schema description, which then will be standardized.

4.3 Example

In order to provide a better understanding of the technical implementation, **Listing 1** partially shows an example scenario definition expressed in the targeted XML format.

Listing 1 Excerpt of a usage scenario defined in a XML-based mission profile format. The full listing is available in reference [1].

```
1   <PortDefinition>
2     <Ports>
3       <Port id="ID.Port.N1" name="N1"
         shortDescription="Electrical device instance
         terminal N1" type="inout"/>
4     <!-- ... -->
5   </PortDefinition>

6   <LoadDefinition>
7     <Loads>
8       <Load id="ID.Load.Env.0"
         shortDescription="Environment temperature T1
         = 298 K for 55 h">
9         <LoadQuantity id="ID.QLoad.Env.0"
           symbol="T1">
10          <SymbolicFunction>
11    <!-- ... -->
12  </LoadDefinition>

13  <ActionDefinition>
14    <Actions>
15      <Action id="ID.Action.0"
         shortDescription="Operating phase 1:
         Resistor operation at 298 K for 55 h">
16        <Assignments>
17          <Assignment
             id="ID.Action.0.Assignment.N1">
18            <PortRefs>
19              <PortRef ref="ID.Port.N1"/>
20            </PortRefs>
21            <LoadRefs>
22              <LoadRef ref="ID.Load.0"/>
23              <LoadRef ref="ID.Load.Env.0"/>
24            </LoadRefs>
25          </Assignment>
26    <!-- ... -->
27  </ActionDefinition>

28  <ActivityDefinition>
29    <!-- ... -->
30  </ActivityDefinition>

31  <ScenarioDefinition>
32    <Scenarios>
33      <Scenario id="ID.Scenario.0">
34        <ActivityFlowSetRefs>
35          <ActivityFlowSetRef
             ref="ID.Activity.FlowSet.0"/>
36        </ActivityFlowSetRefs>
37      </Scenario>
38    </Scenarios>
39    <Application id="ID.Scenario.Application">
40      <ScenarioRefs>
41        <ScenarioRef ref="ID.Scenario.0"/>
42      </ScenarioRefs>
43    </Application>
44  </ScenarioDefinition>
```

In general, a XML document consist of nested elements. Each element begins with a start tag in angled brackets, where its name is directly located after the opening bracket (e.g., element `PortDefinition` on line 1 in **Listing 1**). The corresponding end tag is a sole angled bracket containing a single slash ("/") character followed by the elements name (e.g., `PortDefinition` ends on line 5). An optional variant is a so-called self-closing tag for elements without content, denoted by a slash at the end of the start tag (e.g., the `PortRef` element on line 19 is a self-closing element). An element can have attributes (specified within the element's start tag) and arbitrarily nested children elements between start and end tag.
The `Application` element on lines 39 to 43 describe the actual application of the usage scenario, which requires the definition of several additional aspects of a mission profile, beforehand. Therefore, at the top of the listing the port definitions are defined. An example is the "inout" `Port` "N1" defined on line 3 with an ID for referencing it.
Lines 6 to 12 provide load definitions required for the mission profile scenarios defined later. `Loads` can be simple scalar quantities, such as a fixed voltage as well as complex mathematical constructs like sophisticated functions. Therefore, the MP file format builds on flexible mathematical core concepts (cf. [1]).
`Actions` assign loads to ports by referencing the corresponding definitions (lines 13 to 27). These actions are then used to define `Activities`, which themselves can be finally applied to different `Scenarios`, like the one defined from line 33 to 37 an being used in the aforementioned application.
Due to the lack of space in a single paper, it is not possible to present all details of the MP file format in a single example here. The reader is encouraged to explore [1] and to follow up on future publications of our development group.

5 Summary and Outlook

While appropriately sized design margins used to guarantee the robustness of vehicles in the past, today's growing number and complexity of electro-mechanical parts require the engineers to work much closer to the verge of the parts' specifications. In modern vehicles, highly interdependent mission profiles need to be considered that are caused by distributed architectures, time-dependent self-heating, dynamic power-gating, or system re-configurability. Moreover, much of this information may be distributed at different places along the supply chain. As an example, the mounting location of an ECU is precisely known by the OEM, whereas its internal power distribution is only known by the supplier. However, both need to be known at the same time during the development process. The bidirectional, secure, consistent, and semantically unambiguous data exchange of mission profile information between all partners along the automotive supply chain therefore becomes an essential element to maintain the required quality and reliability of components and systems in future vehicle generations.
Within the German standardization project ELDA-MP [2], 11 industrial and academic partners from the entire supply chain work together on the standardization of the file format MPFO [1] that allows to exchange this kind of mission profile information between all partner of the automotive value chain.

6 Literature

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