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Requirements Management in Automotive: an Empirical Study on Process Improvement Areas

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Abstract— **In the automotive domain the development of software-intensive components is mainly demanded to specialized suppliers that are required by car manufacturers a.k.a. OEMs (Original Equipment Manufacturer) to measure and, eventually, improve their development process by applying process models such as Automotive SPICE. Automotive SPICE is therefore a widely-applied reference framework providing a set of requested practices in the development life-cycle, including requirements management.**

Requirements management is a key issue in automotive because the high volatility of requirements during projects and the need of interactions among different stakeholders. This paper aims at contributing in identifying what are the most frequent weaknesses in requirements management in automotive. The authors present the results of an empirical study aimed at characterizing and analyzing recurrent requirement management weaknesses in automotive. The authors, as Automotive SPICE assessors, have evaluated requirement management practices on the basis of the evidences gathered from real industrial development projects during a significant number of assessments performed at several organizations world-wide.

This paper is intended to derive a picture of the state-of-the-practice of requirements management in automotive focusing on the development of software-intensive automotive components. The purpose is to provide researchers and practitioners with a reference for improvement initiatives aimed at solving those weaknesses.

Index Terms—**Automotive, Process Improvement, Automotive SPICE^{TM}, Requirements Management.**

I. INTRODUCTION

Technological innovation deeply changed automobiles in the last years; modern cars can be regarded in all respects more as complex electronically controlled systems than as mechanical/electro-mechanical devices. Electronic systems, more and more complex and inter-connected, control today the main automobile's functionalities [12]. Consequently, software (with increased demand in terms of size and complexity) is today a crucial car component since it is part of car's components called Electronic Control Units (ECU) that control electronically a large number of the vehicle functions (navigation and infotainment included).

The electronics pervasion influenced the automobile's design and development paradigms. In particular, the development of software is mainly demanded to ECU and software suppliers (OEMs are lately involved more closely) that range from small-medium organizations to large and structured ones. In this context project management and software engineering, initially underestimated sides of the ECU development projects, have at present taken the attention of the whole automotive industry that require projects to meet increasingly demanding timing and quality objectives. In particular, the market expectations (it is fact that the bulk of car issues currently come from electronics and software issues) and technology advances have produced a real need for improvements at managerial and technical levels in order to keep software developments on track, especially for small and medium-sized enterprises (SME).

Automotive SPICE [1] is a model for software process assessment and improvement that is widely used in automotive. Automotive SPICE provides a mean to assess the capability of the ECU suppliers to release products developed by following a technically sound and disciplined process. Automotive SPICE is extensively applied in automotive mainly as a mean for qualifying software suppliers by several OEMs.

Every year hundreds SPICE Automotive assessments are carried out worldwide. The results of these assessments represent a valuable source of information on the state of the art in the development of electronics and software in the automotive industry. Despite this potential wide availability of information, in literature there is, at our understanding, scarceness of studies addressing common trends in such a technologically ever-increasing application domain. The reasons may be different, as the confidentiality of data from assessments and the difficulty of sharing data because the high number of companies and assessors involved.

This paper presents an empirical study based on the information gathered by the authors, as qualified Automotive SPICE assessors, during numerous assessments carried out in the last years worldwide. The study aims at providing a contribution in answering the following research questions:

Q.1 What are the most frequently weak requirements management practices in automotive?

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Q.2 Is there any significant difference, in terms of quality of performance, between the system requirements management and software requirements management in automotive?

This study relies on full sets of data taken from a sample of 34 Automotive SPICE assessments performed by the authors. The average number of processes assessed in these assessments is 13, and for each assessment several projects may be used as sources of information for determining the Capability level of each process. For these reasons, the amount of information and process indicators available from the study sample, although not statistically representative, is significant.

The data sample includes information on several processes ranging from the technical ones (belonging to the Engineering category), as for instance Software Requirements Analysis, Software Design, Software Testing, System Integration and Test processes, to the managerial ones as for instance Problem Resolution Management, Change Management, Risk Management. In this paper, we focus on those processes directly addressing requirements management. According to the Automotive SPICE process reference model, there are two processes directly dealing with requirements management: System Requirements Analysis and Software Requirements Analysis.

Another significant characteristic that enforces the originality and the validity of this empirical study, is the fact that it uses real data from real software development projects collected in the last 7 years. In literature, empirical studies addressing the same topics very often rely on data taken from questionnaires and/or literature review instead of data and indicators from projects [5], [6], [7].

This paper is structured as follows: in Section II the Automotive SPICE model for software process assessment and improvement is presented and its principal components are described. In Section III the methodological approach of this empirical study is presented. Section IV the data, related to the two processes in the scope of such a study, are presented with the support of tables and graphs for understandability and readability purposes. In Section V the available data are analyzed and, finally, in Section VI conclusions are presented and the next steps of this research initiative are introduced.

II. INTRODUCTION TO AUTOMOTIVE SPICE

Automotive SPICE (SPICE stands for *Software Process Improvement and Capability dEtermination*) [1] provides a process framework that disciplines, at high level of abstraction, the software development activities and allows their capability assessment in matching pre-defined sets of numerous process requirements. Automotive SPICE, as a *de-facto* process standard, is used by car manufacturers to push software process improvement among suppliers of software-intensive systems [2]. The purpose of the standard is to provide both a scheme for evaluating the capability of processes and a path for their improvement. Process capability is defined as a characterization of the ability of a process to meet current or projected business goals. Many OEMs are using also this standard to qualify suppliers by requiring to them the achievement of specific ratings [3]. Automotive SPICE standard provides a Process Reference Model and a Process Assessment Model including a Measurement Framework to assign ratings to processes [1].

Applying Automotive SPICE means first to identify an assessment scope (i.e. a set of the processes taken from the Process Reference Model along with a target rating for each of them), then to collect evidences of the way these processes are deployed, and finally, using the mechanism defined in the Process Assessment Model, to derive a rating according to the Measurement Framework.

In practice, the reference Automotive SPICE process scope is the one identified by the VDA (Verband der Automobilindustrie e.V.) [4]. It is composed of a subset of the processes in the Automotive SPICE Process Reference Model, each of them with expected Capability Level 2 or higher. The VDA Scope is the Automotive SPICE benchmark in automotive and the reference scope used by automotive OEMs for the qualification of suppliers of software-intensive car components as well. In TABLE I. the processes of the VDA scope are reported.

TABLE I. AUTOMOTIVE SPICE VDA SCOPE

Process Id. and Name	
ACQ.4	**Supplier monitoring**
SUP.1	**Quality Assurance**
SUP.8	**Configuration Management**
SUP.9	**Problem resolution management**
SUP.10	**Change request management**
MAN.3	**Project management**
SYS.2	**System requirements analysis**
SYS.3	**System architectural design**
SYS.4	**System integration and integration test**
SYS.5	**System qualification test**
SWE.1	**Software requirements analysis**
SWE.2	**Software architectural design**
SWE.3	**Software detailed design and unit construction**
SWE.4	**Software unit verification**
SWE.5	**Software integration and integration test**
SWE.6	**Software qualification testing**

According to Automotive SPICE every process in the assessment scope can be rated according to a scale composed of 6 Levels (ranging from 0 to 5). Level 0 means that the deployment of the process doesn't achieve the expected outcomes and then it is deployed in an incomplete way.

The achievement of Level 1 means that there is evidence that the expected outcomes of that process have been achieved and then the process purpose is achieved as well (Level 1 is said as related to the process Performance). The Levels from 2 to 5 aren't specifically related the achievement of the process purpose, they are instead related to level of management, control, measurement and improvement of the activities related to the process (Levels 2-5 are said as related to the process Capability).

III. THE METHODOLOGICAL APPROACH

During the last seven years the authors, in the capacity of qualified Automotive SPICE Principal Assessor (according to the IntACS international assessor certification scheme) [8], have performed several Automotive SPICE assessments of

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organizations producing software-intensive systems for the automotive industry.

Typically, these Automotive SPICE assessments have targeted the VDA scope (or variants of the VDA scope) in several domains (e.g. body electronics, lighting, closures, ADAS, infotainment, ...).

The table summarizing, in anonymous way, the database that supports this study is available in Annex A. Although the sample is limited in number (34) and geographical distribution (Italy 25, China 2, South Korea 2, Israel 2, U.S.A. 2, Turkey 1) it can be considered meaningful by all means due to the nature of the subject under analysis. Yet the following outcomes have not a statistical validity and are based on empirical observations. In Annex A the column "Company Size" of has been left void for confidentiality reasons (the indication of company size could lead to the identification of the company itself).

The available data target in total 50 projects (some of them having to comply with ISO 26262 requirements as well [9]). From a size point of views the organizations ranges from small, medium and large ones.

During the assessments, evidences and data on the processes in the scope are gathered principally by means of interviews, documents and work products analysis and these data are used to assess (using the expert judgment of the assessors as well) a set of indicators provided by the Automotive SPICE model itself. These indicators are the so-called Base Practices (process-specific indicators) and the Generic Practices (indicators that are applicable to all processes). Base Practices (BPs) are indicators of the performance of a specific process, i.e. they represent the set of practices necessary to fulfil the purpose of the process they refer to. Generic Practices (GPs) are indicators of the capability of a process that are referred to the level of management, control, measurements, and continuous improvement. GPs are out of the scope of this study. In the context of process improvement, it is important to remark that the assessment activity is not limited to a mere rating of process indicators, but it includes also the provision of high-level improvement guidance to fill possible gaps. Assessments are also valuable professional opportunities for the assessors to acquire "behind-doors" knowledge of real projects.

This study is based on the data taken from Automotive SPICE Assessments performed in the time interval 2012-2019.

In 2018 the applicable version of Automotive SPICE moved from 2.5 to 3.1. These two versions are similar, but some differences exist. First, the Process Reference Model changed. Version 2.5 grouped all the engineering processes into the same process Group (called Engineering Process Group, identified by the acronym ENG), version 3.1 splits the engineering processes into two groups: System Engineering Process Group (identified by SYS) and Software Engineering Process Group (identified by SWE). In addition, the Software Engineering Processes in version 3.1 have been arranged on six processes instead of five as in version 2.5 (Figure 2).

As a consequence of that, the mapping between the Automotive SPICE version 2.5 and version 3.1 has been taken into account in order to be able to address correctly the information of interest in assessments made before and after year 2018.

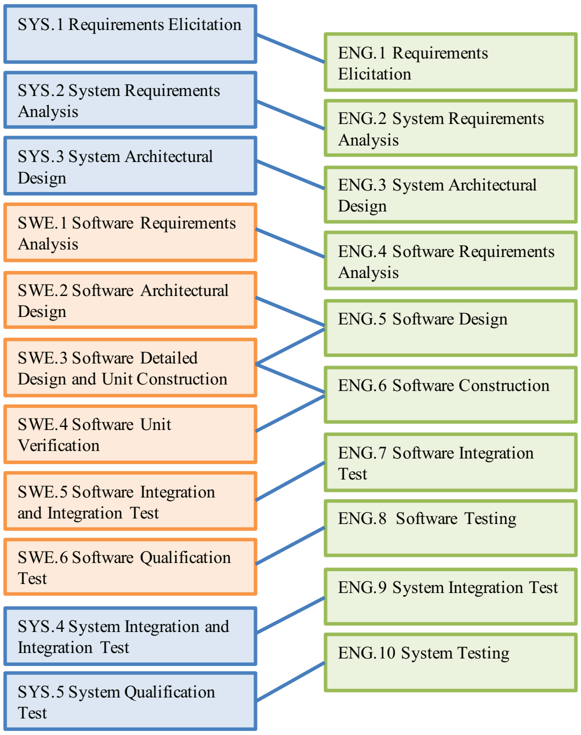

Figure 1: Mapping between Engineering processes in Automotive SPICE ver. 2.5 (right) and 3.1 (left)

The following step-wise approach has been adopted in this study:

S.1 the rating achieved by the Base Practices of the processes assessed according to Automotive SPICE addressed in this study (Annex A) have been collected and reported in tabular format.

S.2 The requirements management-related practices having higher frequency of unsatisfactory ratings (i.e. corresponding to BPs achieving a lower rating according the Automotive SPICE Measurement Framework) have been identified with the support of statistical techniques.

S.3 The rationales of Base Practices weaknesses have been investigated and analyzed in order to identify possible significant trends and commonalities in software requirements management in automotive.

Confidentiality issues has been considered and carefully addressed.

IV. STUDY OUTCOMES

The study reported in this paper focuses on requirements management-related practices. Automotive SPICE has been conceived to include two processes directly addressing requirements management: SYS.2 System Requirements Analysis and SWE.1 Software Requirements Analysis. According to [1] the purpose of the SYS.2 process is "to transform the defined stakeholder requirements into a set of system requirements that will guide the design of the system". The purpose of the SWE.1 process is "to transform the software related parts of

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the system requirements into a set of software requirements". This study addresses both processes in order to provide an answer to the research questions stated in Section I. This section is structured in three sub-sections the first aimed at describing the Base Practices of interest for this study, the second aimed at presenting the raw resulting data of the study, and the third is devoted to the presentation of a preliminary analysis of the study outcomes.

A. Requirements management Practices in Automotive SPICE

Automotive SPICE conceptually distinguishes between system and software requirements. It requires explicitly the existence of two separate sets of requirement specifications, one related to system requirements and the other related to software requirements. The reason of that is that Automotive SPICE has been conceived for targeting suppliers of ECUs (Electronic Control Units) for cars. ECUs are composed of a hardware part with embedded software [10], [11]. In such a context, the system requirements are those related to the functional and non-functional characteristics of the ECU, the software requirements are those related to the software part only.

In TABLE II. and TABLE III. the Base Practices of the System Requirements Analysis and Software Requirements analysis processes are listed and shortly described (each table contain BPs of both Automotive SPICE ver. 2.5 and ver. 3.1).

TABLE II. SYSTEM REQUIREMENTS ANALYSIS PROCESS BASE PRACTICES

ENG.2 System Requirements Analysis process Base Practices (ver. 2.5)	
Id.	Definition
BP1	Document the system requirements in a system requirements specification.
BP2	Analyze system requirements in terms of technical feasibility, risks, and testability.
BP3	Determine the impact of system requirements on the operating environment.
BP4	Prioritize and categorize system requirements
BP5	Evaluate and update system requirements in terms of costs and technical impact.
BP6	Ensure consistency and bilateral traceability of customer requirements to system requirements
BP7	Communicate system requirements to all relevant parties
SYS.2 System Requirements Analysis process Base Practices (ver. 3.1)	
Id.	Definition
BP1	Specify functional and non-functional system requirements starting from stakeholder requirements.
BP2	Structure system requirements (e.g. grouping, sorting, categorizing, prioritizing).
BP3	Analyze system requirements and their interdependencies to ensure correctness, technical feasibility and verifiability.
BP4	Analyze the impact of system requirements on the operating environment
BP5	Develop verification criteria that define the qualitative and quantitative measures for the verification of each system requirement
BP6	Establish bidirectional traceability between stakeholder requirements and system requirements
BP7	Ensure consistency between stakeholder requirements and system requirements
BP8	Communicate agreed system requirements and updates to all relevant parties

TABLE III. SOFTWARE REQUIREMENTS ANALYSIS PROCESS BASE PRACTICES

ENG.4 Software Requirements Analysis process Base Practices (ver. 2.5)	
Id.	Definition
BP1	Document the software functional and non-functional requirements in a software requirements specification.
BP2	Analyze software requirements in terms of technical feasibility, risks, and testability.
BP3	Determine the impact of software requirements on the operating environment.
BP4	Prioritize and categorize software requirements
BP5	Evaluate and update software requirements in terms of costs and technical impact.
BP6	Ensure consistency and bilateral traceability of system requirements to software requirements
BP7	Ensure consistency and bilateral traceability of system architectural design to software requirements
BP8	Communicate software requirements to all relevant parties
SWE.1 Software Requirements Analysis process Base Practices (ver. 3.1)	
Id.	Definition
BP1	Specify functional and non-functional software requirements starting from system requirements and system architecture.
BP2	Structure software requirements (e.g. grouping, sorting, categorizing, prioritizing).
BP3	Analyze software requirements and their interdependencies to ensure correctness, technical feasibility and verifiability.
BP4	Analyze the impact of software requirements on the operating environment
BP5	Develop verification criteria that define the qualitative and quantitative measures for the verification of each software requirement
BP6	Establish bidirectional traceability between software requirements and system requirements and system architecture
BP7	Ensure consistency between stakeholder requirements and system requirements and system architecture
BP8	Communicate agreed software requirements and updates to all relevant parties

B. Study Data Report

TABLE IV. reports, for each assessment, the ratings assigned to the System Requirements Analysis and Software Requirements Analysis Base Practices. In the first column, the assessments belonging to the sample of this study are identified with the same OU Id. reported in Annex A. To be noticed that because the change of the Automotive SPICE reference version from 2.5 to 3.1, some BPs vary in the two versions. For this reason, Table 3 is composed of two parts, the upper part addressing the ratings of BPs in version 2.5, the bottom part those in version 3.1. The measurement scale provided by Automotive SPICE to rate the process indicators is composed of 4 values (N, P, L, F) representing the extent to which a BP is performed. As it is very hard to establish the exact percentage of the performance of a practice (this is not a quantitative measure, it is essentially a professional judgment), Automotive SPICE provides, in order to make assessment rating more repeatable and comparable, the mapping between percentages of performance and rating values on the N-P-L-F scale: N corresponds to a percentage of performance ranging from 0% to 15%, P from 16% to 50%, L from 51% to 85% and F from 86% to 100%.
Then, if the percentage of performance of a certain BP is evaluated, for example as 70%, the rating to be assigned to that BP is L, if the percentage of performance is evaluated as 25% the rating is P, and so on. In practice, the assessors shall gather

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evidences enough to establish at what extent a BP is performed, this extent is required to be expressed in percentage and then moved in the N-P-L-F scale.

As shown in TABLE IV. , the available data for System Requirements Analysis process are less than those for Software Requirements Analysis process. This is due to the variability of assessment scopes in the study sample. To facilitate the analysis of the data the rating value of each BP, originally expressed by a value in the four-value scale N-P-L-F, is substituted by a numeric value. In order to substitute values with numbers, we introduce an assumption: we consider the mean value of each percentage range and we substitute it to the correspondent N-P-L-F value.

TABLE IV. REQUIREMENTS MANAGEMENT-RELATED BASE PRACTICES RATING

OU Id.	**ENG.2 Base Practices**								**ENG.4 Base Practices**							
	BP1	**BP2**	**BP3**	**BP4**	**BP5**	**BP6**	**BP7**		**BP1**	**BP2**	**BP3**	**BP4**	**BP5**	**BP6**	**BP7**	**BP8**
1	-	-	-	-	-	-	-		F	L	L	L	L	L	L	F
2	F	L	L	F	L	L	F		F	L	L	F	P	F	F	F
3	F	L	F	F	F	F	F		F	L	F	F	F	F	F	F
4	F	P	F	L	L	F	F		F	F	F	F	F	L	P	F
5	P	P	L	P	L	L	L		P	P	L	P	L	L	L	F
6	F	L	F	F	L	F	L		P	L	L	L	L	P	L	L
7	L	L	P	L	L	L	F		F	L	L	P	P	F	L	F
8	-	-	-	-	-	-	-		F	L	L	F	F	F	F	F
9	-	-	-	-	-	-	-		F	L	L	L	F	F	F	F
10	-	-	-	-	-	-	-		F	F	L	F	F	F	F	F
11	-	-	-	-	-	-	-		F	L	L	F	F	F	F	F
12	-	-	-	-	-	-	-		F	L	L	F	F	F	F	F
13	-	-	-	-	-	-	-		F	F	F	F	L	F	F	F
14	-	-	-	-	-	-	-		F	L	L	L	F	F	L	F
15	F	P	F	F	L	P	F		F	P	F	F	L	F	F	F
16	-	-	-	-	-	-	-		F	L	F	L	F	F	F	L
17	-	-	-	-	-	-	-		F	L	L	F	F	F	F	F
18	-	-	-	-	-	-	-		P	P	L	P	P	P	P	F
19	P	P	L	P	P	P	F		L	P	L	F	L	P	P	F
20	-	-	-	-	-	-	-		F	P	F	F	F	L	L	F
21	-	-	-	-	-	-	-		F	F	L	F	F	L	F	F
22	-	-	-	-	-	-	-		F	F	L	P	L	P	L	L
26	F	L	L	F	L	F	F		F	F	L	L	L	F	F	F
27	L	L	L	F	L	F	F		F	P	P	F	L	F	F	F
29	F	L	L	F	F	F	F		L	L	L	L	L	L	L	F
OU Id.	**SYS.2 Base Practices**								**SWE.1 Base Practices**							
	BP1	**BP2**	**BP3**	**BP4**	**BP5**	**BP6**	**BP7**	**BP8**	**BP1**	**BP2**	**BP3**	**BP4**	**BP5**	**BP6**	**BP7**	**BP8**
23	F	L	F	P	N	L	L	F	F	F	F	F	L	L	L	F
24	F	F	F	F	L	F	F	L	F	F	F	L	L	F	F	L
25	F	F	F	L	F	F	F	F	F	F	L	F	F	F	F	F
28	F	F	F	F	L	F	F	F	F	F	F	L	L	F	F	F
30	-	-	-	-	-	-	-	-	F	F	L	L	F	F	F	F
31	L	F	F	N	F	L	F	F	F	F	F	L	L	L	L	F
32	F	F	F	L	N	F	F	F	F	F	F	F	P	F	F	F
33	F	F	L	P	N	L	L	F	F	L	P	P	N	P	P	F
34	P	L	P	L	P	L	L	F	L	L	F	F	L	F	L	F

According to this mechanism, the N rating will be substituted with the value 0,075 (7,5%), P with 0,33 (33%), L with 0,66 (66%), and F with 0,925 (92,5%). According to this assumption, it is possible to calculate the average value of the ratings of each BP in the sample of this study. The average values are represented in graphical format in Figure 2.

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Figure 2: Average Rating of Single Base Practices

C. Study Data Analysis

A characteristic of the two of processes related to requirements management in Automotive SPICE is that they contain BPs with similarities. In particular, we can notice that the BPs of these processes (belonging to Automotive SPICE ver. 2.5 and ver. 3.1) can be grouped into 6 clusters that represent homogeneous areas of practices. Each cluster is composed of practices conceptually addressing homogeneous topics. Clusters represent data aggregation that allows to overcome the problem of the mapping between Automotive SPICE ver. 2.5 and 3.1 for the purpose of this study.

The clusters that can be identified are:

C1 Identify/Specify requirements.
C2 Structure/prioritize/organize requirements
C3 Perform analysis.
C4 Define Verification Criteria for requirements.
C5 Establish traceability and assure consistency.
C6 Communicate requirements.

In TABLE V. the BPs (both of Automotive SPICE ver.2.5 and ver. 3.1) belonging to each cluster are reported.

Interesting outcomes can be derived by aggregating the BP belonging to the same cluster and by calculating the mean value of the ratings. The results are represented in graphical format in Figure 3 (note that, for readability reasons, the y-scale starts from 40%).

TABLE V. CLUSTER COMPOSITION

Cluster	System Requirements BPs	Software Requirements BPs
C1	ENG.2: BP1, SYS.2: BP1	ENG.4: BP1, SWE.1: BP1
C2	ENG.2: BP4, SYS.2: BP2	ENG.4: BP.4, SWE.1: BP2
C3	ENG.2: BP2, BP.3, BP.5 SYS.2: BP3, BP4	ENG.4: BP2, BP.3, BP.5 SWE.1: BP3, BP4
C4	SYS.2: BP5	SWE.1: BP.5
C5	ENG.2: BP6 SYS.2: BP6, BP7	ENG.4: BP6, BP7 SWE.1: BP6, BP7
C6	ENG.2: BP7, SYS.2: BP8	ENG.4: BP8, SWE.1. BP8

It can be noticed that the mean values of the rating of the C.3, C.4, are significantly lower than those of the other clusters. It indicates that the performance of the practices belonging to these clusters is weaker for the organizations in the study sample.

The information that can be derived from the sole average, is significant because it is able to identify the BPs having an average lower rating with respect to the others in the sample, and then that they are, generally speaking, the hardest to be deployed in projects.

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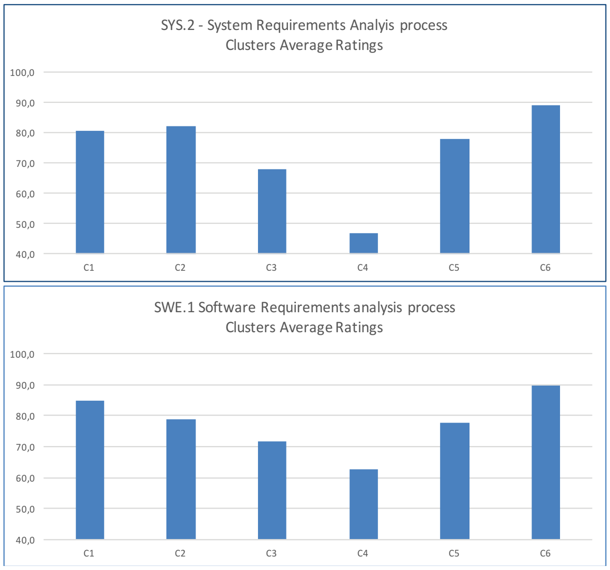

Figure 3. Average Ratings by Base Practices Clusters

V. CONCLUSIONS

This paper presents an empirical study aimed at identifying and discussing possible recurrent weak and strong areas in the overall requirements management process in automotive. The study has been carried out using data from Automotive SPICE assessment performed using real data from real software development project. The study uses data gathered from 34 Automotive SPICE Assessment performed in the last 7 years by the authors. In such a time frame, Automotive SPICE moved from version 2.5 to version 3.1, the mapping between these two versions has been addressed anyway in the study.

The overall requirements management process is addressed by two different processes in Automotive SPICE: System Requirements Analysis, and Software Requirements Analysis processes. It has been noticed that the Base Practices of these processes can be clustered by the requirement management activity they refer to. In total 6 clusters have been identified for each process. Each cluster contains Base Practices that refer to the same kind of activities.

The results of the study, reported in detail in this paper, can be summarized as follows:

1. The study shows that the ratings of the Base Practices are not homogeneous. Some Base Practices are weaker than others. In particular, for software requirements management, the BPs with the lower average rating are: SWE.1.BP5 "Develop Verification Criteria" and SWE.1.BP4 (along with the corresponding ENG.4.BP3 for version 2.5): "Analyze the impact on the operating environment". This in line with the author experience, in fact the most common weaknesses, with respect Automotive SPICE, found during the assessment are related to the establishment, at requirement definition phase, of the criteria to be used for verifying (at verification time) their correct implementation. In practice, the found evidences of this practices are often limited to the indication the type of verification activity (testing, inspection, audit, analysis, …) to execute, while what is expected here, to be fully compliant, is the specification of the verification environment, possible special conditions, and existing/potential constraints. The other common weakness is about the performance of the analysis aimed at evaluate the impact of the software requirements on the surrounding environment (that in the case of ECU is represented by the system resources and the hardware/software interfaces).
2. The second interesting result is the evidence about the average ratings achieved by the clusters. Data show that cluster C3 (Perform Analysis) and C4 (Verification Criteria) are weaker than the others both for system requirements and software requirements. Moreover, the average rating of C4 for system requirements is significantly lower than the rating of C4 for software requirements. Again, this is a confirmation of the authors' experience. In fact, in practice, in automotive there is a wide and quite uniform usage of requirement management tools that support requirements definition, classification, organization and traceability. That makes the practices associated to clusters C1, C2, C5 and C6 well supported by the technology and then generally mature. On the contrary, as the requirements are generally defined in natural language, the tool support for the analysis activities is poor. In other words, as the analysis (both the analysis aimed at verifying the correctness of requirements, their impact, and the related verification criteria) is an activity performed basically in a manual way, it is harder to achieve higher ratings.
3. The third significant result is the evidence that there is not a big difference between the average ratings achieved by the practices related to software requirements and system requirements (with the only exception of C4). That confirms again the authors' experience, in fact the procedures and tools used for system requirements engineering are very often the same used for software requirements engineering.

The research question Q.1 is addressed by 1. and 2., the research question Q.2 is addressed by 3.

The authors, on the basis of their experience in leading Automotive SPICE assessments and with the support of the results of the empirical study presented in this paper, identified some general improvement directions in automotive requirements engineering. As the weaker practices (i.e. Analysis and Determination of Verification Criteria) are performed mostly applying human-based, manual activities with limited benefits from the use of automated tools, the improvement shall be addressed mostly from a methodological perspective. In other words, significant improvements can be achieved by systematically introducing the use of well-defined, mature analysis techniques (extensively applied in functional safety critical contexts) as for instance HAZOP [13] or FMEA [14] (or derivations of them). Such techniques may lead to a systematic analysis, not only addressing the 'how' the requirements are specified, but also addressing the impact of these requirements both with respect to the architectural design (at system and at software level) and

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in terms of functional behaviour and scenarios of use in the target operational context.

The study presented in this paper doesn't claim to rely on a statistical valid set of data and consequently it doesn't claim a statistical validity of the results. The study relies on a data set taken from Automotive SPICE process assessments performed by the authors on a sample of 34 companies worldwide in the last seven years. These data include evidences collected during the assessments related to procedures, work products, tools, software product characteristics, quality and management indicators. The data available for system requirements management are less than those for software requirements. This is due to the fact that the assessment scopes are not homogeneous and depends on the business scope of the organization unit assessed.

The principal originality of this study is the use of real data from real software development projects in automotive. In literature, the empirical studies addressing similar topics are mainly based on literature reviews and surveys made by means of questionnaires.

The results of this study can represent a contribution in the identification of the most critical practices in automotive software development projects and can represent both a benchmark for automotive software players and a starting point for setting up process improvement initiatives.

The authors' aim is to continue this study by extending the analysis to other processes available in the data sample and investigating possible correlations among BPs. The sample will be used also to find out possible characterizations of the weaknesses in terms of company size, the geographical location and the specific product domain.

REFERENCES

[1] VDA QMC Working Group 13 / Automotive SIG Automotive SPICE Process Assessment / Reference Model Ver. 3.1, 2017

[2] Hoermann K., Mueller M., Dittman L., Zimmer J.: Automotive SPICE in Practice: Sur-viving Implementation and Assessment. Rocky Noor, 2008.

[3] Fabbrini, F., Fusani, M., Lami, G., Sivera, E.: A SPICE-based Supplier Qualification Mechanism in Automotive Industry. Software Process Improvement and Practice Journal. 2007; 12; 523-528. Wiley InterScience.

[4] VDA: Automotive SPICE Guidelines. 1st Ed. H. Druck, 2017.

[5] Niazi M., Wilson D., Zowghi D.: Critical Success Factors for Software Improvement Implementation: An Empirical Study. in Software Process Improvement and Practice. Wiley InterScience, vol. 11, pp.193-211. 2006.

[6] Niazi M., Ali Babar M., Verner J. M.: Software Process Improvement barriers: A cross-cultural comparison. In Information and Software Technology. Elsevier vol. 52 (2010), pp. 1204-1216. 2010.

[7] Hall T., Rainer A., Baddoo N.: Implementing Software Process Improvement: An Empirical Study. In Software Process Improvement and Practice. Wiley InterScience, vol 7; pp. 3-15. 2002.

[8] INTACS Homepage, www.intacs.info, last accessed 2019/11/08.

[9] ISO 26262 - Road Vehicles - Functional Safety, International Organization for Standardization, 2011.

[10] Moessinger J.: Software in Automotive Systems. IEEE Software 27(2) (2010).

[11] Denton, T.: Automobile Electrical and Electronic Systems. 5th Ed. Routledge (2017).

[12] C. Ebert, J. Favaro Automotive Software. IEEE Software May-Jun. 2017, pp. 33-39, vol. 34.

[13] Redmill, F., Chudleigh, M. System Safety: Hazop and Software Hazop. John Wiley & Sons Inc. (1999).

[14] Ericson, C.A. Hazard Analysis Techniques For System Safety. Wiley-Interscience (2005).

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Annex A

Study Sample description:

OU Id.	Domain	Project Team Size	OU size	Company size	Location	year	scope
OU.1	body electronics	8	10		Italy	2013	ENG.4, ENG.5, ENG.6, ENG.8, MAN.3, SUP.1, SUP.8, SUP.9, SUP.10 (CL2)
OU.2	Infotainment & Telematics	20	27		China	2014	ENG.2, ENG.3, ENG.4, ENG.5, ENG.6, ENG.7, ENG.8, ENG.,9, ENG.10, MAN.3, MAN.5, MAN.6, SUP.1, SUP.8, SUP.9, SUP.10 (CL2)
OU.3	Electric vehicle Control	25	1013		Korea	2014	ENG.2, ENG.3, ENG.4, ENG.5, ENG.6, ENG.7, ENG.8, ENG.,9, ENG.10, MAN.3, SUP.1, SUP.8, SUP.9, SUP.10 (CL2)
OU.4	Electric vehicle Control	25	18		Korea	2014	ENG.2, ENG.3, ENG.4, ENG.5, ENG.6, ENG.7, ENG.8, ENG.,9, ENG.10, MAN.3, SUP.8, SUP.10 (CL2)
OU.5	Electric Steering	8	10		Italy	2014	ACQ.4, ENG.1, ENG.2, ENG.3, ENG.4, ENG.5, ENG.6, MAN.3, MAN.5, SUP.1, SUP.4, SUP.8, SUP.9, SUP.10, SPL.2 (CL2)
OU.6	body electronics	4	5		Italy	2013	ENG.1, ENG.2, ENG.3, ENG.4, ENG.5, ENG.6, ENG.7, ENG.8, ENG.,9, MAN.3, MAN.5, SUP.1, SUP.4, SUP.8, SPL.2 (CL2)
OU.7	body electronics	10+	31		Italy	2012	ACQ.4, ENG.1, ENG.2, ENG.3, ENG.4, ENG.5, ENG.6, ENG.7, ENG.8, ENG.9, ENG.10, MAN.3, MAN.5, SUP.1, SUP.8, SUP.9, SUP.10 (CL2)
OU.8	Cooling Fan	9	10		Italy	2013-2014	ENG.4, ENG.5, ENG.6, ENG.7, ENG.8, MAN.3, SUP.1, SUP.8, SUP.9, SUP.10 (CL2)
OU.9	Lighting Control	6	10		Italy	2013-2014	ENG.4, ENG.5, ENG.6, ENG.7, ENG.8, MAN.3, SUP.1, SUP.8, SUP.9, SUP.10 (CL3)
OU.10	Window lift	10	50+		China	2014	ENG.4, ENG.5, ENG.6, ENG.7, ENG.8, MAN.3, SUP.1, SUP.8, SUP.9, SUP.10 (CL2)
OU.11	Driving Assistance	20+	100+		Israel	2013	ENG.4, ENG.5, ENG.6, ENG.7, ENG.8, MAN.3, SUP.1, SUP.8, SUP.9, SUP.10 (CL2)
OU.12	Closures	7	10		Italy	2013	ENG.4, ENG.5, ENG.6, ENG.7, ENG.8, MAN.3, MAN.5, MAN.6, SUP.1, SUP.8, SUP.9, SUP.10 (CL2)
OU.13	Electric Pumps	7	10		Italy	2013	ENG.4, ENG.5, ENG.6, ENG.7, ENG.8, MAN.3, SUP.1, SUP.8, SUP.9, SUP.10 (CL2)
OU.14	Cooling Fan	5	5		Italy	2012	ENG.4, ENG.5, ENG.6, ENG.7, ENG.8, MAN.3, MAN.5, MAN.6, SUP.1, SUP.8, SUP.9, SUP.10 (CL2)
OU.15	body electronics	7	20		Italy	2012	ENG 2, ENG.3, ENG 4, ENG 5, ENG 6, ENG 7, ENG 8, ENG 9, ENG10, SUP.1, SUP 8, SUP 9, SUP 10, MAN 3 CL3
OU.16	Window lift	4	5		Italy	2012	ENG.4, ENG.5, ENG.6, ENG.7, ENG.8 (CL2)
OU.17	Electric vehicle Control	8	20		Italy	2010-2012	ENG.4, ENG.5, ENG.6, ENG.7, ENG.8, MAN.3, SUP.1, SUP.8, SUP.9, SUP.10 (CL2)
OU.18	body electronics	8	12		Italy	2016	ENG.1, ENG.4, ENG.5, ENG.6, ENG.7, ENG.8, MAN.3, MAN.5, MAN.6, SUP.1, SUP.4, SUP.8, SUP.9, SUP.10, SPL.2 (CL2)
OU.19	Infotainment & Telematics	10	20		Italy	2015	ACQ.4, ENG.4, ENG.5, ENG.6, ENG.7, ENG.8, MAN.3, MAN.5, MAN.6, SUP.1, SUP.4, SUP.8, SUP.9, SUP.10, SPL.2 (CL2)
OU.20	body electronics	4	6		Italy	2015	ENG.4, ENG.5, ENG.6, ENG.7, ENG.8,MAN.3, SUP.1, SUP.8, SUP.9, SUP.10 (CL2)
OU.21	HVAC	10	10+		Italy	2018	SWE.1, SWE.2, SWE.3, SWE.4, SWE.5, SWE.6, MAN.3, SUP.1, SUP.8, SUP.9, SUP.10 (CL2)
OU.22	body electronics	10+	100+		USA	2019	SWE.1, SWE.2, SWE.3, SWE.4, SWE.5, SWE.6, MAN.3, SUP.1, SUP.8, SUP.9, SUP.10 (CL2)
OU.23	Driving Assistance	50+	100+		Israel	2019	SY2.2, SYS.3, SYS.4, SYS.5, SWE.1, SWE.2, SWE.3, SWE.4, SWE.5, SWE.6, MAN.3, SUP.8, SUP.9, SUP.10 (CL2)
OU.24	HVAC	10	100+		Italy	2016	ACQ.4, ENG.1, ENG.2, ENG.3, ENG.9, ENG.10, MAN.3, MAN.5, SUP.1, SUP.4, SUP.8, SUP.9, SUP.10, SPL.2 (CL2)
OU.25	power train	15	100+		Italy	2018	SY2.2, SYS.3, SYS.4, SYS.5, SWE.1, SWE.2, SWE.3, SWE.4, SWE.5, SWE.6, MAN.3, SUP.1, SUP.8, SUP.9, SUP.10 (CL2)
OU.26	Lighting systems	25	100+		Italy	2018	ENG.2, ENG.3, ENG.4, ENG.5, ENG.6, ENG.7, ENG.8, ENG.,9, ENG.10, MAN.3, SUP.1, SUP.8, SUP.9, SUP.10 (CL2)
OU.27	engine cooling	10	100+		Italy	2017	ENG.2, ENG.3, ENG.4, ENG.5, ENG.6, ENG.7, ENG.8, ENG.,9, ENG.10, MAN.3, SUP.1, SUP.8, SUP.9, SUP.10 (CL2)
OU.28	body electronics	20	100+		Turkey	2018	SYS.1, SY2.2, SYS.3, SYS.4, SYS.5, SWE.1, SWE.2, SWE.3, SWE.4, SWE.5, SWE.6, MAN.3, MAN.5, SUP.1, SUP.2, SUP.4, SUP.8, SUP.9, SUP.10, SPL.2, ACQ.4 (CL2)
OU.29	body electronics	10+	50+		Italy	2016	ENG.1, ENG.2, ENG.3, ENG.4, ENG.5, ENG.6, ENG.7, ENG.8, ENG.,9, ENG.10, MAN.3, MAN.5, SUP.1, SUP.8, SUP.9, SUP.10, ACQ.4 (CL2)
OU.30	Instrument Cluster	10	10+		Italy	2017	ENG.4, ENG.5, ENG.6, ENG.7, ENG.8, MAN.3, SUP.1, SUP.8, SUP.9, SUP.10(CL2)
OU.31	Instrument Cluster	10+	50+		Italy	2019	SY2.2, SYS.3, SYS.4, SYS.5, SWE.1, SWE.2, SWE.3, SWE.4, SWE.5, SWE.6, MAN.3, SUP.1, SUP.8, SUP.9, SUP.10 (CL2)
OU.32	body electronics	10+	50+		Italy	2019	SY2.2, SYS.3, SYS.4, SYS.5, SWE.1, SWE.2, SWE.3, SWE.4, SWE.5, SWE.6, MAN.3, SUP.1, SUP.8, SUP.9, SUP.10 (CL2)
OU.33	body electronics	10	10+		Italy	2019	SY2.2, SYS.3, SYS.4, SYS.5, SWE.1, SWE.2, SWE.3, SWE.4, SWE.5, SWE.6, MAN.3, SUP.1, SUP.8, SUP.9, SUP.10 (CL2)
OU.34	Instrument Cluster	10+	50+		USA	2019	SY2.2, SYS.3, SYS.4, SYS.5, SWE.1, SWE.2, SWE.3, SWE.4, SWE.5, SWE.6, MAN.3, SUP.1, SUP.8, SUP.9, SUP.10 (CL2)

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