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Standardization of quality and reliability tests in the auto-parts industry: a structured approach concerning thermal systems

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Abstract

In the automotive industry, first-tier suppliers play an important role, as they often establish long-term partnerships with multiple car-makers, for developing and supplying complete car modules.

One of the conditions underlying these partnerships is the quality and reliability of car modules. To achieve it, car-makers generally require multiple tests, often on 100% of the parts subcontracted. The number of tests required can be very high, even for modules with a relatively low level of customization. Also, the configuration of the tests can vary significantly from a car-maker to one other, even for the same test typologies.

The aim of this paper is presenting a decision-support tool for the standardization of quality and reliability tests, which uses some already available information on previous tests (e.g., about their effectiveness, cost and simplicity of execution) and involves experts both from the supplier's and car-makers' staff. Test standardization is guided by a simple procedure based on two steps: (i) grouping the tests required by different car-makers into typologies of homologous tests, with a similar protection level in terms of product and quality reliability, and (ii) determining the most appropriate configuration for each test typology.

The description of the methodology is based on a real case-study concerning a worldwide supplier of thermal systems.

Keywords: Quality and reliability test, Auto-parts, First-tier supplier, Car module, Standardization, Test effectiveness, Thermal systems.

1. Introduction and problem definition

Since several decades, outsourcing plays a strategic role in the automotive industry (Franceschini et al. 2003). Most of car-makers tend to build long-term partnership alliances with a relatively limited number of first-tier suppliers, who are gaining more and more responsibility in the development of entire car modules (e.g., engines, transmissions, braking systems, seats, tyres, etc.) and their integration in the final product (Aláez-Aller and Longás-García 2010).

This tendency, accelerated by the recent socio-economic crisis, pushed suppliers in joining forces either through mergers, acquisitions and joint ventures, so as to establish highly specialized and

efficient organizations serving a large number of car-makers (Schaede, 2010, Tsu-Ming, Fan-Yun & Kai-I, 2013).

For simplifying the design and manufacturing stage without compromising product customization, auto-parts suppliers generally develop a relatively small number of multifunctional modules/platforms (Minhas et al. 2011). From the perspective of car-makers, ordering a complete module reduces the number of parts to be outsourced and thus the time of assembly, quality control cost, labour and administrative cost.

In the after-sales service, car-makers generally collect the so-called Voice of the Customer (VoC) (Franceschini 2002; Sireli et al. 2007; Mavridou et al., 2013), to have an indication on the customer satisfaction with the full "package" (i.e., the final product plus additional services, such as maintenance program, roadside assistance, etc.). This information is strategic for car-makers oriented at developing new products or improving the existing ones according to the real customer requirements (van Driel and Dolfsma 2009). Sharing this information with suppliers, at least those of the most "strategic" modules, is an important issue for consolidating partnerships. From the perspective of suppliers, this constant flow of information is essential to guide the quality improvement of the parts subcontracted, in accordance with the philosophy of "continuous improvement" (Delbridge and Barton 2002).

Another condition to reinforce the partnership between suppliers and car-makers is the quality and reliability of modules, which can have a very strong impact on the customer's quality perception of the final product. For example, a survey of an Italian car-maker showed that the majority of customer complaints, relating to city-cars, concerned the performance of the heating-ventilating-and-air-conditioning (HVAC) unit (Bassotto et al. 2005)! For achieving reliability, car-makers generally require several tests, which should be carried out by suppliers often on 100% of the parts supplied (Zhiqiang, Yuejun , Xiaole, 2013).

This paper will focus on a case-study concerning quality and reliability tests on thermal systems (e.g., electric compressors, HVAC units, radiators, etc.) produced by an important worldwide supplier, with a plant based in Northern Italy. For reasons of confidentiality, the company will be kept anonymous and hereafter denominated with the acronym DTS. DTS supplies a large number of car-makers, such as Fiat, General Motors, PSA, Renault, Volkswagen, etc., and, by tradition, gives great importance to the product reliability.

It is worth noting that a scarcely debated issue in the scientific literature is that of the great variety of tests required by car-makers to their suppliers. This variability is twofold:

1. In terms of test *typologies*. The total number of test typologies (i.e., groups of tests aimed at testing the same function/attribute) can be very high, especially for parts subject to prolonged

and continuous use. In addition, similar tests can be considered as important by some car-makers and neglected by others.

2. In terms of test *configurations*. For tests of the same typology, parameters (e.g., number of cycles, temperature, pressure, etc.) can vary significantly from a car-maker to one other. The practical implication is that tests of the same typology may be more or less effective, expensive or simple to execute, depending on the configuration requested by car-makers.

The variety of test typologies and configurations can be large even for parts, such as thermal systems, with a relatively low level of customization. This apparent paradox is explained by the fact that car-makers generally develop their test practices individually. This generates a certain "affection" for the practices in use and a consequent reluctance towards the introduction of possible changes (Pil and MacDuffie 1999). Several existing techniques and procedures can be used for assessing the capability of suppliers to (i) perform the tests imposed by a car-maker and (ii) manufacture parts that satisfy these tests as much as possible; one of the most popular is the Production Part Approval Process (PPAP), developed by the Automotive Industry Action Group (AIAG) as part of the Advanced Product Quality Planning (APQP) manual (AIAG, 2006; Franceschini et al., 2011). On the other hand, suppliers can hardly play an active role in reducing test variety because of the lack of unified standards defining tests univocally and thoroughly. As a result, managing quality and reliability tests may be complicated for multiple reasons:

- Need for different types of test beds, some of which dedicated to just a few tests.
- Flexibility of the operators, who must be able to switch from one configuration to one other (on single or multiple test beds) without making mistakes.
- Risk of biased conclusions about the actual reliability of the parts investigated, due to the fact that different test configurations can be more or less effective; for example, a part passing the test by one car-maker could not pass that by another one.
- Operating costs likely to grow.

The previous considerations highlight the need for reducing the variety of tests in a rational way. The objective of this paper is the introduction of a simple standardization procedure based on two main steps: (i) grouping the tests required by different car-makers into typologies of homologous tests, with a similar protection level in terms of product reliability, and (ii) determining the most reasonable and appropriate configuration for each test typology.

The proposed procedure uses the results of previous tests and the opinion of experts – i.e., engineers and/or technicians – both from the supplier's and the car-makers' staff.

The remainder of this paper is organized in two sections. Sect. 2 illustrates in detail the standardization procedure, providing an application example to reliability testing on radiators

produced by DTS. The concluding section summarizes the original contribution of the manuscript and discusses the advantages and limitations of the proposed procedure.

2. Methodology

Tab. 1 summarizes the phases of the proposed procedure, which are described individually in the following subsections. The description is based on a case-study concerning tests on radiators supplied by DTS to four worldwide car-makers (CM_1 to CM_4). For reasons of confidentiality, car-makers are kept anonymous.

Phase denomination	Input	Output	Subjects involved
2.1 Identification of test typologies	Technical specifications concerning the tests required by the car-makers	List of the test typologies, with their individual configurations	A team of experts on reliability tests from DTS staff
2.2 Determination of the importance level of test typologies	Questionnaires submitted to experts	Judgements defined on a 5-level ordinal scale	Experts on reliability tests both from the staff of DTS and that of each car-maker
2.3 Comparison of the alternative configurations (for each individual test typology)	-	-	-
2.3.1 Definition of judgements relating to each configuration	Results of previous reliability tests and questionnaires submitted to experts	Judgements defined on 5-level ordinal scales (concerning effectiveness, cost, simplicity of execution)	A team of experts on reliability tests from DTS staff
2.3.2 Selection of the most suitable configuration	Judgements resulting from phases 2.2 e 2.3.1	Selection of a configuration for each test typology	A team of experts on reliability tests from DTS staff

Tab. 1. Typical phases of the test standardization procedure, specifying input/output data and subjects involved.

2.1 Identification of test typologies

One of the most delicate phases of the procedure is the classification of the tests imposed by various car-makers into groups of homologous tests. Consistently with the definition of *reliability*, i.e., "the ability of a system or component to maintain its functions/attributes under stated conditions for a specified period of time" (O'Connor 2002), homologous tests should be focused at testing the maintenance of similar functions/attributes (e.g., corrosion resistance, sealing, etc.). Unfortunately, this classification is complicated by the fact that there is no standard to define the set of functions/attributes of a generic system uniquely. We take the liberty to clarify this issue through a similarity between the concept of *measurement* and that of *reliability test*.

A measurement is an operation for estimating an attribute of a real entity (e.g., the length of an object), using an appropriate instrument (e.g., a tape, a calliper, a laser interferometer or an echo sounder). Results of measurements obtained by different instruments can be compared since they are linked to the same reference unit (e.g., in the case of length measurements, the meter). This link

originates from the instrument calibration process, which establishes a connection between the measurement result and the reference unit by an unbroken metrological traceability chain (JCM200:2012 2012). Of course, the results of measurements performed using different instruments may differ in several aspects, such as accuracy, cost, simplicity of execution, etc..

On the other hand, reliability tests can be viewed as special measurements for assessing the ability of a component to maintain a certain function/attribute over time. Even considering the same function/attribute, there can be different instruments (test beds) and procedures (configurations of test parameters) to test it, as evidenced by the variety of tests suggested by different car-makers. Unfortunately, the results of tests performed with different instruments and/or procedures are not easy to compare for at least two reasons: (i) the difficulty in identifying the functions/attributes of a system uniquely, and (ii) the lack of standard references for establishing the conditions in which evaluating the maintenance of these functions/attributes.

The large variety of tests imposed by various car-makers is also reflected by their denominations: in most cases, car-makers use acronyms or reference numbers referred to internal procedures.

A possible way to overcome these limitations (at least partially), allowing comparisons among tests suggested by different car-makers, is to create typologies of homologous tests. This activity can be carried out by a team of experts, consisting of engineers and/or technicians with a deep experience and knowledge of the tests of interest.

Tests of the same typology will differ in several aspects, such as effectiveness – defined as the ability of the test to reveal the maintenance of a certain function/attribute, in a realistic operational context – cost, simplicity of execution, etc.. We are aware that the definition of test typologies is a subjective operation. However, the fact that it is carried out by a team of multiple experts represents a partial guarantee for obtaining reasonable results.

Tab. 2 lists the test typologies defined by the team of experts from DTS staff. It can be seen that test typologies are variegated; about half of them are required by the majority of car-makers but only 9 out of 28 are shared by all of them. Also, there are several tests required by few or even individual car-makers. Those requested by unique car-makers (highlighted in gray in Tab. 2) were not taken into account.

Ref. no.	Test typology denomination	CM_1	CM_2	CM_3	CM_4
T_1	Bursting test	×	×	✓	✓
T_2	Drain packing	×	✓	×	×
T_3	Draincock	✓	✓	✓	×
T_4	External corrosion (salt spray)	✓	✓	✓	✓
T_5	External corrosion (severe wastewater analysis)	✓	✓	✓	✓
T_6	Fluid cooler heat exchange	×	✓	×	×
T_7	Functional characteristics	×	×	✓	×
T_8	General characteristics	×	×	✓	×
T_9	Internal cleanliness	✓	✓	✓	✓
T_{10}	Internal corrosion	✓	✓	✓	✓
T_{11}	Leak	✓	✓	✓	✓
T_{12}	Long life coolant resistance	×	✓	×	×
T_{13}	Low Temperature	✓	✓	✓	×
T_{14}	Performance measurement	✓	✓	✓	✓
T_{15}	Phys./Chem./ Environm./Mech.	×	×	✓	✓
T_{16}	Pollution	×	×	×	✓
T_{17}	Pressure cap wear	✓	×	×	×
T_{18}	Pressure cycle durability	✓	✓	✓	✓
T_{19}	Pressure resistance	×	✓	×	×
T_{20}	Resistance to fastening dowels	×	✓	×	×
T_{21}	Resistance to fluid attack	×	×	×	✓
T_{22}	Resistance to gravelling	×	×	×	✓
T_{23}	Resistance to painting	×	×	✓	✓
T_{24}	Rubber seal	×	✓	×	×
T_{25}	Temperature endurance	×	×	✓	×
T_{26}	Thermal cycle durability	✓	✓	✓	✓
T_{27}	Vacuum	✓	×	×	✓
T_{28}	Vibration durability	✓	✓	✓	✓

Tab. 2. List of the test typologies concerning radiators manufactured by DTS, sorted alphabetically by their denomination. Test typologies required and non-required by each of the car-makers (CM_1 to CM_4) are respectively marked by the symbols "✓" and "×". The test typologies highlighted in grey are required by unique car-makers and therefore will not be taken into account in the rest of the analysis.

2.2 Determination of the importance level of test typologies

The level of importance of a test typology depends on the negative effects, which may originate from the loss of the function/attribute investigated. This judgement may change from a car-maker to one other. For example, test typology "T_{11}–Leak" is regarded as very important by the totality of the car-makers, because leakage from the radiator can rapidly lead to compromising its main function of cooling the car engine. Instead, some car-makers consider the typology "T_{10}–Internal corrosion" as important, while others do not.

This judgement was collected by questionnaires submitted to experts in reliability tests, both from the DTS' and car-makers' staff. Experts from the car-makers were engineers and/or technicians dealing with DTS for technical issues about the tests of interest. Judgments were collected for DTS and each of the four car-makers separately.

To make judgments as simple as possible, it was adopted a 5-level ordinal scale (see the second column in Tab. 3). The category N/A (not applicable) was assigned to car-makers not requiring the test typology of interest.

Level	Importance (of a test typology)	Effectiveness (of a configuration)	Cost (of a configuration)	Simplicity (of a configuration)
1	Not at all important	Not at all effective	Very high cost	Not at all simple
2	Low importance	Low effectiveness	High cost	Low simplicity
3	Medium importance	Medium effectiveness	Medium cost	Medium simplicity
4	High importance	High effectiveness	Low cost	High simplicity
5	Very high importance	Very high effectiveness	Very low cost	Very high simplicity
N/A	Not applicable	Not applicable	Not applicable	Not applicable

Tab. 3. Definition of the 5-level scales used for evaluating (i) the importance of a test typology and (ii) the effectiveness, cost and simplicity of execution of the relevant test configurations.

In order to facilitate the formulation of judgments, we provided respondents with the results of a previous *Failure Mode, Effects, and Criticality Analysis* – FMECA (Bouti and Kadi 1994) on the radiator, which identified and prioritized the main failures.

It is reasonable to assume that the major test typologies are those investigating the maintenance of functions/attributes potentially affected by the most critical failures. Tab. 4 illustrates the results of the questionnaires for each test typology. The most important typologies at global level are those requested by a large number of car-makers and those with relatively high importance judgements.

For each test typology, it is possible to determine the median[1] level of importance:

$$\tilde{I} = median\,(I_i)\,, \tag{1}$$

being I_i the importance levels assigned by experts from DTS and each of the car-makers (if applicable). Precisely, subscript $i \in \{DTS\} \cup A$, where $A \subseteq \{\mathrm{CM}_1, \mathrm{CM}_2, \mathrm{CM}_3, \mathrm{CM}_4\}$ indicates groups of experts from the subset of car-makers requiring the test typology of interest. E.g., the test typology T_1 is required by CM_3 and CM_4, but not by CM_1 and CM_2, therefore A={CM_3, CM_4}.

Test ref. no.	I					$\tilde{I}$
	DTS	CM_1	CM_2	CM_3	CM_4	
T_1	4	N/A	N/A	5	4	4
T_3	1	1	2	1	N/A	1
T_4	3	5	3	4	4	4
T_5	3	4	4	5	5	4
T_9	2	1	1	3	1	1
T_{10}	1	4	3	1	1	1
T_{11}	4	4	5	5	5	5
T_{13}	3	2	1	2	N/A	2
T_{14}	5	5	5	3	2	5
T_{15}	1	N/A	N/A	1	1	1
T_{18}	5	5	5	4	4	5
T_{23}	3	N/A	N/A	2	4	3
T_{26}	5	4	5	5	5	5
T_{27}	4	5	N/A	N/A	3	4
T_{28}	3	5	5	5	2	5

Tab. 4. Judgements of experts from DTS and four car-makers (CM_1 to CM_4) on the importance of the test typologies in Tab. 2. $\tilde{I}$ is the median the importance values relating to each test typology.

[1] Using the average value as a central tendency indicator may be inappropriate since I_i values are defined on an ordinal scale (Stevens 1946).

$\tilde{I}$ will be used in the next stages of the procedure (see the last column of Tab. 4). For simplicity, it was assumed that judgements by the groups of experts from DTS and each of the car-makers have the same relevance.

It can be noticed that, even for tests of the same typology, there can be significant differences between the judgements by different respondents. This is probably the result of their specific experience on previous tests.

2.3 Comparison of the alternative configurations

2.3.1 Definition of judgments relating to each configuration

In this phase, the attention is focussed on the configurations imposed by different car-makers for each of the test typologies selected in Sect. 2.1. For the purpose of example, Tab. 5 reports the configurations concerning to the test typologies "T_1–Bursting test" and "T_{26}–Thermal cycle durability".

Test typ.	CM_1	CM_2	CM_3	CM_4
T_1	N/A	N/A	Fill radiator with test fluid; Increase pressure at 4bar/min, up to 3.5bar; Hold this pressure for 30s.	Pressure ≤ (1.5*inlet pressure); Increase pressure at 0.1bar/s, up to 3.5bar; Hold this pressure for 300s; Ambient temperature: 23±5 °C.
T_{26}	No. of cycles: 1000; Coolant temperature: from 0°C to 100±2°C; Pressure: 130±10kPa.	No. of cycles: 7000; 50% water 50% coolant as medium; Coolant temperature: from 20 °C (30 s max) to 90 °C (2 min) and to 20°C (2 min) with flow rate 40 l/min.	No. of cycles: 1000; Cycle rate: 7 cycles/h; Coolant temperature: from -30 °C to 100 °C; Pressure: 1.3 bar.	No. of cycles: 2500; Pre-conditioning: 2 h at 20 °C; Ambient temperature: 23±5 °C; High temperature of coolant: 113 °C; Low temperature of coolant: 23 °C; Switch duration between high and low temperature phase: 5 s;

Tab. 5. Configurations of the test parameters for test typologies "T_1–Bursting test" and "T_{26}–Thermal cycle durability", from the perspective of four car-makers (CM_1 to CM_4).

For each of these configurations, different aspects were investigated. The first one is the test's level of *effectiveness* in detecting possible abnormalities of the part in maintaining its functions/attributes. The survey was carried out by submitting questionnaires to a team of DTS experts, already involved in the activities described in Sects. 2.1 and 2.2.

Again, judgements were defined on a 5-level ordinal scale (see the third column in Tab. 3). In general, it was assumed that the most effective tests tend to be severe/conservative, generating a significant amount of "false positives", i.e., parts that did not pass the test, while being functionally acceptable (in statistical terms, a greater type-I error). Therefore, very high levels of effectiveness are justified only for test typologies of high importance, for which it can be reasonable to minimize the probability of "false negatives" (in statistical terms, the type-II error), i.e., parts with deteriorated function(s)/attribute(s), which passed the test. Tab. 6 shows the resulting judgements

(see the column "Eff", for each car-maker).

Respondents were subsequently asked to judge the level of *cost* and *simplicity* of execution of each configuration. Cost, which generally depends on test time and hourly cost of equipment/operator(s), is quite simple to estimate. On the other hand, simplicity – which may depend on the complexity of test set-up, risk of human error, operators' degree of familiarity with the equipment, etc. – is more difficult to quantify. These judgements were defined on two 5-level scales (see the fourth and fifth column in Tab. 3). The scale related to cost is "reversed", so that low and high levels have a negative and positive connotation respectively. Tab. 6 shows the resulting judgements (see the columns "Cost" and "Simpl" for each car-maker).

Test	$\tilde{I}$	CM_1			CM_2			CM_3			CM_4			Selected
Ref. No.		Eff	Cost	Simpl	Eff	Cost	Simpl	Eff	Cost	Simpl	Eff	Cost	Simpl	config.
T_1	4	N/A	N/A	N/A	N/A	N/A	N/A	3	2	2	5	3	2	CM_4
T_3	1	3	1	3	2	2	2	1	3	3	N/A	N/A	N/A	CM_3
T_4	4	3	2	2	4	4	2	5	4	2	5	2	2	CM_2
T_5	4	4	1	2	5	2	1	5	1	2	4	1	1	CM_1
T_9	1	3	2	1	1	1	3	1	1	1	3	3	1	CM_2
T_{10}	1	4	5	5	2	5	5	1	3	4	2	5	5	CM_3
T_{11}	5	3	4	3	5	4	4	5	5	5	4	3	3	CM_3
T_{13}	2	1	2	1	1	1	1	1	1	2	N/A	N/A	N/A	CM_2[(1)]
T_{14}	5	4	4	2	2	3	2	3	2	4	3	2	4	CM_1[(1)]
T_{15}	1	N/A	N/A	N/A	N/A	N/A	N/A	1	3	4	3	2	1	CM_3
T_{18}	5	4	5	5	3	4	5	4	5	3	4	5	4	CM_1[(1)]
T_{23}	3	N/A	N/A	N/A	N/A	N/A	N/A	5	2	3	4	1	1	CM_4
T_{26}	5	3	3	4	5	4	5	4	4	3	5	3	5	CM_2
T_{27}	4	2	1	1	N/A	N/A	N/A	N/A	N/A	N/A	5	1	1	CM_4
T_{28}	5	4	1	1	4	1	2	4	2	2	3	1	1	CM_3[(1)]

[(1)] In this case, $Eff_i < \tilde{I}$ for all the alternative configurations; as a result, Eq. 2 can not be applied. The selected configuration is the one with $max(Eff_i)$.

Tab. 6. Judgments of experts from DTS about the degree of effectiveness (Eff), cost and simplicity of execution (Simpl) of the test configurations proposed by any of the car-makers (CM_1 to CM_4). The last column shows the configuration selected according to the procedure described in Sect. 2.3.2.

2.3.2 Selection of the most suitable configuration

Among the possible configurations, the "best" is selected according to the procedure illustrated in the flowchart in Fig. 1.

As shown, in the case there are two (or more) configurations that satisfy the condition

$$min(Eff_i \mid Eff_i \geq \tilde{I}), \tag{2}$$

being $i \in A$, i.e. the subset of car-makers requiring the test typology of interest, the selection continues by applying a lexicographic order based on cost and simplicity of execution. In the unlikely event of a further tie, the final decision would be determined manually by the team of expert.

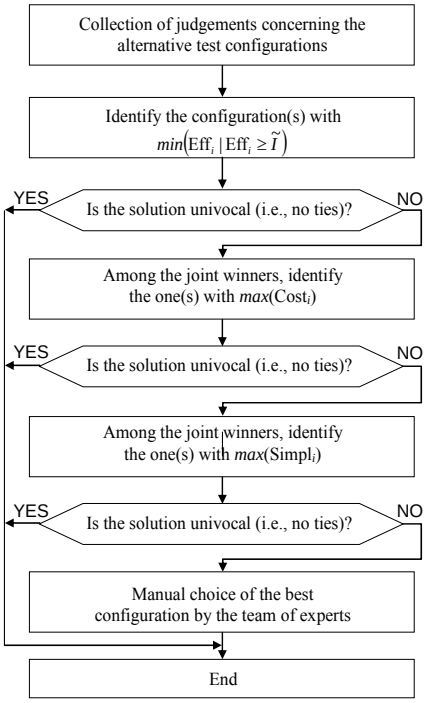

Fig. 1. Flowchart depicting the procedure for selecting the "best" configuration, for a certain test typology.

The last column in Tab. 5 reports the configurations selected applying the previous procedure.

For the purpose of example, as regards T_9, two are the configurations satisfying Eq. 2: CM_2 and CM_3. Since these two alternatives have the same cost level (i.e., 1), the selection is determined by simplicity of execution, which is higher for CM_2 (i.e., 3) with respect to CM_3 (i.e., 1).

The logic of selection seen above is based on several assumptions:

- The best configuration is not defined "from scratch", instead it is selected among those imposed by the car-makers. Defining the parameters of a test is actually a very delicate operation because of the multiplicity of factors (e.g. as regards radiator: number of cycles, temperature, pressure, composition of coolant, etc.), which may affect its effectiveness. These factors and their possible interactions should be examined rigorously by experimental plans (Box et al. 1978). It was assumed that the test configurations were defined by the car-makers following this approach.
- It was assumed that test effectiveness and severity, i.e., the probability to generate "false positives", go hand in hand. The fact that the selected configuration should have a level of effectiveness as close as possible to that of $\tilde{I}$ prevents from selecting (i) tests that are too severe with respect to their relatively low importance, or (ii) tests that are not very effective, despite their relatively high importance. The authors are aware that, in some cases, this assumption may not be realistic. For example, there could exist very effective configurations with relatively low incidence of "false positives". When, on the basis of its experience, the team of expert feels that this hypothesis should be relaxed, one could select the configuration satisfying the condition:

max(Eff_i). (3)

Also, Eq. 3 could be used when there is no configuration satisfying Eq. 2, because $\text{Eff}_i < \tilde{I}$ $\forall i \in A$ (see tests T_{13}, T_{14}, T_{18} and T_{28} in Tab. 6).

- Among the three types of judgements (effectiveness, cost, simplicity) related to the configurations, it was implicitly assumed the ordering Eff > Cost > Simpl (symbol ">" means "preferred to"). However, the technique based on lexicographic ordering could be replaced by more complex techniques, such as Multi-Criteria Decision-Making (MCDM) methods (Franceschini et al. 2007; Köksalan et al. 2011).

3. Final remarks

This work focused on the problem of the standardization of reliability tests for auto-parts suppliers. This problem originates from (at least) two reasons: (i) in general there are no unified standards defining exhaustive and univocal sets of tests, and (ii) any car-maker requires a set of tests, with *ad hoc* configurations deriving from their specific experience and work practices.

The proposed procedure is a first attempt to address this problem in a simple and economic way. A more elegant and sophisticated approach would be that of designing new optimal configurations, in terms of effectiveness, through rigorous design of experiments (DoE). Unfortunately, the price to pay would be too high because of the large number of experiments required. On the contrary, the proposed technique exploits a large amount of information already available (i.e., results of previous tests) and the expertise of engineers and/or technicians from suppliers and car-makers.

The procedure was applied in DTS on a number of thermal systems, such as radiator, HTVC, heater core, etc., focussing on the test configurations imposed by several worldwide car-makers. The example presented in this paper illustrated the philosophy behind the procedure.

Thanks to its simplicity and low cost, the procedure was judged by DTS staff as very useful and easy to implement. For this reason, it will be extended to other components manufactured by the company. The proposed methodology can be considered as a decision-support tool for rationalizing the management of reliability tests for auto-parts suppliers, which is complementary to other procedures, such as the AIAG's APQP/PPAP (AIAG, 2006).

The proposed approach has some limitations, summarized as follows:

- Test standardization is *internal* with respect to a specific supplier, since it depends on the degree of expertise of engineers/technicians, the information regarding previous tests, the available equipment (test beds) and the variety of tests imposed by car-makers. As a consequence, the application of the procedure to different suppliers could lead to different results, even considering homologous parts.

- Several phases of the procedure are subjective, such as the interpretation of the results of previous tests or the formulation of judgments. To avoid disputes, these phases should be carried out in a transparent manner, involving technical staff with a certain expertise on reliability tests, both from suppliers and car-makers.
- The procedure can be applied to auto-parts with a relatively low degree of customization, where comparing tests related to similar product models is not hasty.
- Standardized tests may be rejected by some car-makers, who are "attached" to their configurations. However, the results of the proposed procedure may be used for persuading the most reluctant car-makers to accept standardized tests, as they will probably be more effective, cheaper and simpler than other ones.

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References

AIAG (2006) Production Part Approval Process, 4th Edition (PPAP-4). Automotive Industry Action Group (AIAG), Cincinnati, OH.

Aláez-Aller, R., Longás-García, J.C. (2010) Dynamic supplier management in the automotive industry. International Journal of Operations and Production Management, 30(3): 312-335.

Bassotto, C., Daprile, F., Davanzo, G., Franceschini, F., Maisano, D., Spirito, F. (2005) Customer Satisfaction: spunti per l'analisi in automatico di reclami o di lamentele su prodotti/servizi. Qualità, XXXV(1-2): 35-38.

Box, G.E.P., Hunter, W.G., Hunter, J.S. (1978) Statistics for Experimenters, New York: Wiley, 1978.

Bouti, A., Kadi, D.A. (1994) A state-of-the-art review of FMEA/FMECA. International Journal of Reliability, Quality and Safety Engineering, 1(4): 515-543.

Delbridge, R., Barton, H. (2002) Organizing for continuous improvement: Structures and roles in automotive components plants. International Journal of Operations and Production Management, 22(6):680-692.

Franceschini, F. (2002) Advanced Quality Function Deployment, St. Lucie Press/CRC Press LLC, Boca Raton, FL.

Franceschini F., Galetto M., Pignatelli A., Varetto M. (2003) Outsourcing: guidelines for a structured approach. Benchmarking, 10(3): 246-260.

Franceschini, F., Galetto, M., Maisano, D. (2007) Management by Measurement: Designing Key Indicators and Performance Measurement Systems. Springer, Berlin

Franceschini F., Galetto M., Maisano D., Mastrogiacomo L. (2011) ISO/TS 16949: analysis of the diffusion and current trends. Proceedings of the Institution of Mechanical Engineers, Part B, Journal of Engineering Manufacture, 225(5): 735-745.

JCM200:2012 (2012) International Vocabulary of Metrology (VIM) – Basic and General Concepts and Associated Terms.

Köksalan, M., Wallenius, J., Zionts, S. (2011) Multiple criteria decision making: from early history to the 21st century. World Scientific, Singapore.

Mavridou E., Kehagias D., Tzovaras D., Hassapis G., (2013) Mining affective needs of automotive industry customers for building a mass-customization recommender system. Journal of Intelligent Manufacturing, 24:251-265,

Minhas, S.U.H., Lehmann, C., Berger, U. (2011) Concept and Development of Intelligent Production Control to enable Versatile Production in the Automotive Factories of the Future. Glocalized Solutions for Sustainability in Manufacturing: Proceedings of the 18th CIRP International Conference on Life Cycle Engineering, Technische Universität Braunschweig, Braunschweig, Germany, May 2nd-4th, 2011, 57-62

O'Connor, P.D.T. (2002) Practical Reliability Engineering (4th ed.), New York: Wiley.
Pil F.K., MacDuffie, J.P., (1999) What makes transplants thrive: managing the transfer of "best practice" at Japanese auto plants in North America. Journal of World Business, 34(4): 372-391.
Schaede, U. (2010) Globalisation and the reorganisation of Japan's auto parts industry. International Journal of Automotive Technology and Management, 10(2-3/2010): 270-288.
Sireli, Y., Kauffmann, P., Ozan, E. (2007) Integration of Kano's model into QFD for multiple product design. IEEE Transactions on Engineering Management, 54(2): 380-390.
Stevens, S.S. (1946) On the Theory of Scales of Measurement. Science, 103(2684): 677-680.
Tsu-Ming Yeh , Fan-Yun Pai & Kai-I Huang (2013) The critical factors for implementing the quality system of ISO/TS 16949 in automobile parts industry in Taiwan. Total Quality Management & Business Excellence, 24(3-4): 355-373
van Driel, H., Dolfsma, W. (2009) Path dependence, initial conditions, and routines in organizations: The Toyota production system re-examined. Journal of Organizational Change Management, 22(1): 49-72.
Zhiqiang L., Yuejun Z., Xiaole H. (2013) Integrating run-based preventive maintenance into the capacitated lot sizing problem with reliability constraint. International Journal of Production Research, 51(5): 1379-1391.