APTA approach: Analysis of accelerated prototype test data based on small data volumes within a car door system case study

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Abstract: Knowledge of failure behavior and failure modes regarding the component´s complete life cycle is fundamental within the early development phases of technical and complex products. Here, an overview of the design of prototype test procedures as well as the transformation of expected field failure behavior in prototype test characteristics is described. This provides the required knowledge for the understanding of accelerated testing and is the basis for understanding of the developed “Accelerated Prototype Test data Analysis” (APTA) approach. The APTA approach is demonstrated with the help of a case study with regard to a car door system. The analysis of the design principles, expected impacts in the usage phase and car door prototype test procedure is discussed. With the use of nonparametric as well as parametric statistical methods, the wearing and ageing of specific door mechanism characteristics (e.g. forces or displacements) in relation to life span variables are analyzed. Furthermore a method for the comparison of qualitative and quantitative characteristics and their impact on the door system is described. Finally the interpretation of the results and deduction of general issues and recommendations regarding to the design of prototype test procedures are presented.

Keywords: Accelerated Life Test, (Non-) parametric statistics, product reliability, prototype test data analysis

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1. INTRODUCTION

Continuously increasing functionality of components and products as well as their complexity lead to complex failure modes and failure behavior. This applies particularly to the automotive industry: Car systems and components of the technical disciplines like electronic/electric, powertrain, auto body (interior/exterior) and chassis which are characterized by growing complexity and functionality. The goal is the detection of product risks and the analysis of the product and component reliability. Hence, the challenge is the analysis of the potential prospective customer usage conditions and their transformation in prototype test procedures during the product development process. Furthermore, the low number of prototypes - mainly due to financial limits - causes a major problem: From a statistical point of view, the validity of the test results based on a low test data volume is considerable. E.g. parametrical distribution models are unverifiable and subsequently parametric significance tests are not applicable.

The estimation of the failure behavior and failure prediction of highly reliable technical products is a very complex and difficult process. New, modern products are developed with a service life of many years, in plenty of cases in permanent running. Competitive national as well as international markets demand the reduction of the time-to-market point, which results in shorter product development and testing times. Within shorter innovation cycles and high customer requirements it is hardly possible to test the products under the normal conditions in a feasible time. The usage of Accelerated Tests (ATs) reduces the testing times and offers a solution for the detection of failure modes. Understanding of the AT models and its applications as well as adequate analysis of the product and selection of the right statistical methods in the design phase combined with the knowledge of testing methods is essential for the development of the right testing strategy. Choosing the proper test strategy will cause in the reduction of development time, number of prototypes and cost.

This paper shows the analysis of life span variables of a car fleet during the usage phase. This is the base of operations for the correlation analysis between prototype accelerated testing and usage phase. Furthermore the limits of parametric and applications/advantages of nonparametric statistics are discussed. Lastly, the interpretation of the results and deduction of general issues and recommendations regarding to the design of prototype test procedures are presented.

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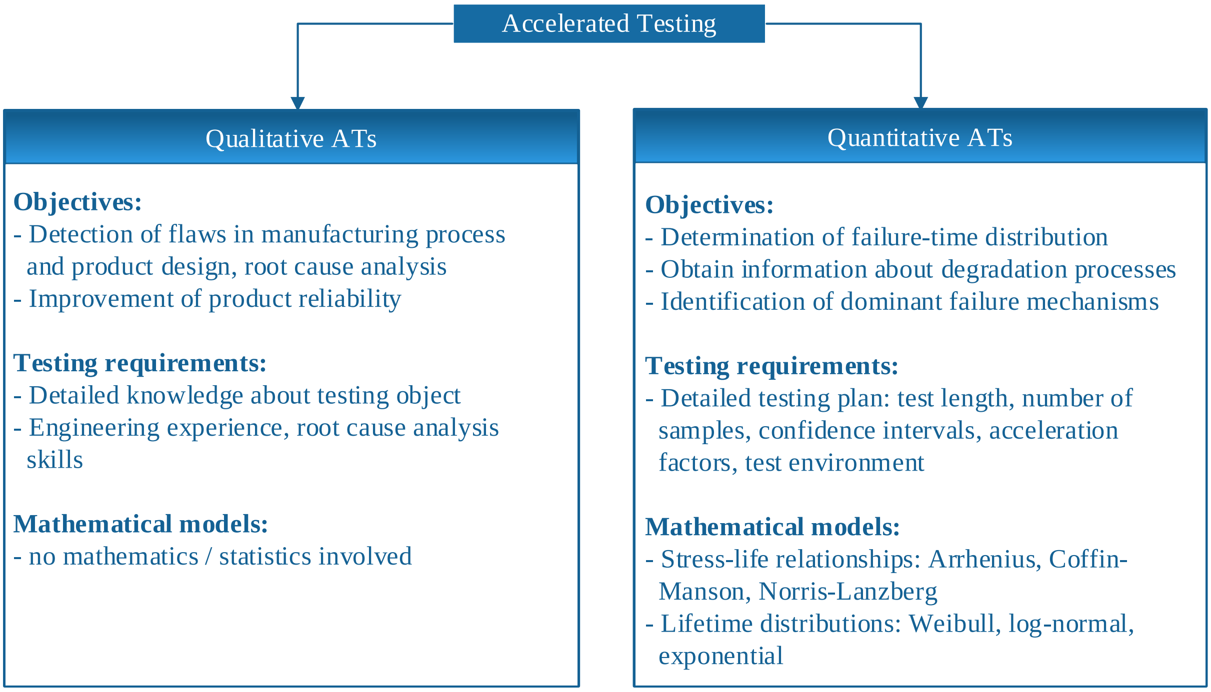
2. PRINCIPALS OF ACCELERATED TESTING

This chapter focuses on theoretical principals and application areas of accelerated testing procedures. Based on these theoretical aspects the analysis of the main characteristics regarding the test cycle within the case study “car door system” is performed. Both areas, accelerated testing theory and case study test method, are the fundamentals of operations with respect to the APTA approach in chapter 3.

2.1. Comparison of testing methods

According to [3], “Accelerated tests” (ATs) is a term used for two completely different kinds of tests which both have different purposes, “qualitative ATs” and “quantitative ATs”. The key differences are presented briefly in figure 1.

Figure 1: Accelerated testing methods



Accelerated Testing

Qualitative ATs

Objectives:
- Detection of flaws in manufacturing process and product design, root cause analysis
- Improvement of product reliability

Testing requirements:
- Detailed knowledge about testing object
- Engineering experience, root cause analysis skills

Mathematical models:
- no mathematics / statistics involved

Quantitative ATs

Objectives:
- Determination of failure-time distribution
- Obtain information about degradation processes
- Identification of dominant failure mechanisms

Testing requirements:
- Detailed testing plan: test length, number of samples, confidence intervals, acceleration factors, test environment

Mathematical models:
- Stress-life relationships: Arrhenius, Coffin-Manson, Norris-Lanzberg
- Lifetime distributions: Weibull, log-normal, exponential

Qualitative ATs are used to identify product weaknesses caused by flaws in the product´s design or manufacturing process. This is done by gradually increasing stresses until the product fails. The aim is to improve the product reliability in a very short period of time, usually hours or days. They are mostly performed on entire systems but can be performed on individual assemblies as well. Common names for this type of tests are HALT (Highly Accelerated Life Test), STRIFE (Stress-Life) and EST (Environmental Stress Testing) [11].
An essential component of qualitative ATs is root cause analysis. It needs to be determined whether the identified potential flaws can happen in the field or if they are caused by testing a product above / below its specification levels and changing the failure mechanism. Based on this analysis corrective action is eventually implemented to improve the product reliability. Tests of this type do not involve any statistical or mathematical methods. They are only used to make the product more robust, not to gain any knowledge about the product lifetime or the degradation process over time.

Quantitative ATs are used to obtain information about the failure-time distribution and degradation in a relatively short period of time (usually weeks or months) by accelerating the use environment. In most cases a model to describe the relationship between failure mechanism and accelerating variables already exists. They are also well-suited for finding dominant failure mechanisms and are usually performed on individual assemblies rather than full systems. In order to set up a quantitative AT, several different parameters must be known, for example test duration, number of samples, desired confidence intervals, field and test environment, stress-life relationship and distribution model.

2.2 Acceleration models

One key factor is to determine the acceleration factor. It can be obtained by two different methods, either by using existing physical / chemical acceleration models or by determining empirical acceleration models by experimentation.

Physical / chemical acceleration models
Various physical / chemical models for well-understood failure mechanisms are already available. They describe the failure-causing process and allow extrapolation to use conditions for specific environment variables. The relationship between accelerating variables and the actual failure mechanism is usually extremely complicated. However simple models which adequately describe the process already exist. Examples for some acceleration models can be found in [3].

Empirical acceleration models

If there are no chemical / physical models to describe the failure-causing processes adequately it may be necessary to develop an own empirical model by experimentation. An empirical model usually provides an excellent fit to the available data, but still can provide false extrapolations for working conditions. Extensive empirical research regarding possible failure mechanisms and different stress variable combinations is needed to justify the needed extrapolation.

2.3. Acceleration methods

Increasing the use rate: Products, that are not in continuous use, can be accelerated by increasing the usage rate. This means that the time between the load phases is reduced. It has to be considered whether the increased use rate changes the cycles to failure distribution. A toaster for example could heat up increasingly cycle after cycle until it reaches temperatures which would not appear under normal use conditions. A case study for this purpose was performed by [4].

Increasing the aging-rate: By increasing experimental variables like temperature, humidity or radiation, chemical processes that lead to certain failure modes can be accelerated (e. g. the chemical degradation of a PV module can be accelerated by inducing an electric potential).

Increasing the level of stress: If the environmental stress exceeds the strength of the testing object, the unit (prototype) will fail. This means that a unit operating at higher stress levels will generally fail after a shorter space of time than a unit at lower stress levels (e.g., amplitude in temperature cycling, voltage, or pressure).

2.4 Types of responses

Accelerated tests can be distinguished based on the type of response as following:

- **Accelerated Binary Tests (ABTs):** The response of an ABT is binary, so the only reliability information obtained from each unit is whether it has survived the test or not, cf. [3].

- **Accelerated Life Tests (ALTs):** The response of an ALT is directly related to the lifetime of the product at use conditions. In most cases ALT data are right censored because the test is stopped before all units fail. If failures are only discovered during periodic inspection times the ALT response is interval censored, cf. [6] for a comprehensive overview of ALTs.

- **Accelerated Repeated Measures Degradation Tests (ARMDTs):** In an ARMDT the degradation of a unit is measured at several different points in time. This information is used to extrapolate the lifetime of the testing object. The degradation response could be actual chemical or physical degradation or performance degradation. An example for ARMDT modelling and analysis can be found in [7].

• **Accelerated Destructive Degradation Tests (ADDTs):** ADDTs are similar to ARMDTs, except that the measurements are destructive, so only one observation per test unit can be obtained. A discussion of the ADDT method and a detailed case study can be found in [8].

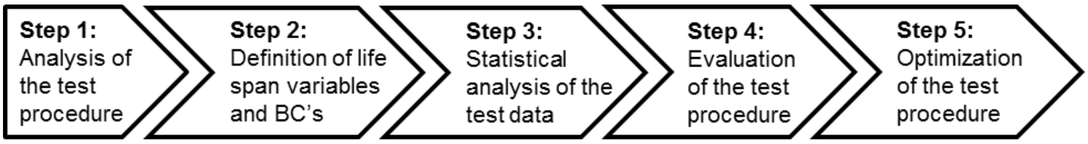
These different kinds of ATs are often closely related because they can involve the same failure mechanisms and physical / chemical model assumptions. However they are different regarding the statistical models and analyses which are performed because of the different kinds of observed responses. An important attribute of all quantitative ATs is the necessity to extrapolate to lower stress levels. Tests are performed in an environment with accelerated conditions, but estimates are needed at use conditions.

The test used in the case study "car door system" is a collection of worst-case scenarios of different use types and markets. Because of the irregular test plan it is not possible to perform a profound prognosis by using existing acceleration models. The purpose of the test procedure is only to ensure that the product does not fail at higher stress levels. For now the data is not used to extrapolate to normal use conditions. To do this, it would be advised to rearrange the test procedure to follow some of the more commonly used stress profiles like constant-stress or step-stress.
Studies to create appropriate testing plans were already done in the past, e. g. [9]. Because of that, the statistical analysis of the prototype data is only used to compare the different prototypes themselves as well as the two test facilities. In addition, test characteristics can be correlated and the impact of simulated environment influences can be evaluated quantitatively.

3. APTA APPROACH

In this chapter, the theory and application of the developed APTA approach is shown. First, in chapter 3.1 the authors outline an overview regarding the essential APTA procedure. Subsequently, the five APTA approach steps are explained in detail by an application within the case study with regard to a car door system (cf. chapter 3.2 – 3.6).

Figure 2: APTA approach



3.1. Overview of fundamental steps of the APTA approach

The "Accelerated Prototype Test data Analysis (APTA)" approach is a tool for definition, analysis, evaluation and optimization of existing test procedures and its application for the common as well as next generation products in all application areas, were testing plays a major role in the development process. It is a five step bottom-up algorithm with the main focus on:

- (Non-) parametric analysis of the test data regarding similarities/differences in the tested products and life span variables
- Analysis of the test procedure in order to detect its weak and strong points
- Optimization of the test procedure and optionally a prognosis of the system performance

With regard to the definition of APTA (figure 1) the single steps are to be characterized as follows.

Step 1: Analysis of the test procedure should answer the following questions: What is the testing product? Where is it tested? What are the relevant environmental influences? How many tested objects exist? How many testing machines are available? Are there similarities between the products (e.g. left-right variants or symmetrical design)? Are the samples independent? Answers to these questions are fundamental for the choice of proper statistical methods.

Step 2: This step includes a definition and allocation of life span variables with at least more than 10 measurements. Furthermore the boundary conditions which influence the measured product should be defined and classified.

Step 3: According to step 1, the statistical methods have to be chosen in a proper way. For this purpose distribution tests (e.g. Kolmogorov-Smirnov, Shapiro-Wilk, Anderson-Darling or Chi-squared test) [1] are the base of operations in order to choose either parametric or nonparametric methods. Normal distribution of all life span variables is the requirement for the use of many parametric tests whereas nonparametric statistics can be used without any knowledge of the distribution model regarding the data base. In spite of the wide application possibility of nonparametric methods which are more conservative, there is an information loss of about 15% [12].

Step 4: Based on step 1 and 2, the test procedure can be evaluated. Hence, a system of equations with BCs defined as unknowns and measurements as right-hand side has to be solved. Solution of this problem provides the impact of every single BC on each life span variable.

Step 5: With the solution of step 4 the test procedure can be optimized. A further development of the system behavior according to the test plan can be predicted.

Table 1: Boundary conditions and results of the tests

Boundary condition	Unknown	Result Force	Result displacement
Temperature T1, Humidity H1	x1	15.3	1.3
Temperature T2, Humidity H1	x2	-803.4	-82.4
Temperature T3, Humidity H1	x3	736.1	76.7
Temperature T4, Humidity H1	x4	-72.7	-16.7
Temperature T5, Humidity H2	x5	75.5	8.8
Temperature T6, Humidity H1	x6	2.8	-0.2
Temperature T7, Humidity H2	x7	31.2	-4.4
System adjustment	x8	-18.4	-4.2
Particle 1	x9	-601.9	-70.5
Erasure of particle 1	x10	534.5	64.7
System wash	x11	318.6	28.8
Particle 2	x12	-181.6	-14.3
Erasure of particle 2	x13	-46.3	-5.6
Additional stress of the system	x14	-1744	-174.3
Particle 3	x15	1655.7	162

The introduced APTA approach will be explained with the help of a case study involving a car door mechanism which is an assembly of multiple separate components. The used data in form of measurements is anonymized. Nevertheless, the presented findings correspond to the real, physical performance effects and failure behavior. The applied boundary conditions are an example of a composite of qualitative and quantitative parameters which can stress a door mechanism and are representative loads of an automotive usage phase. However, the focus of this paper is the optimized analysis of small data and information volumes. The optimization of the test procedure and its prognosis doesn’t play the key role of this research. The mechanism will be explained on the basis of the five steps of the approach in the following chapters 3.2 to 3.6.

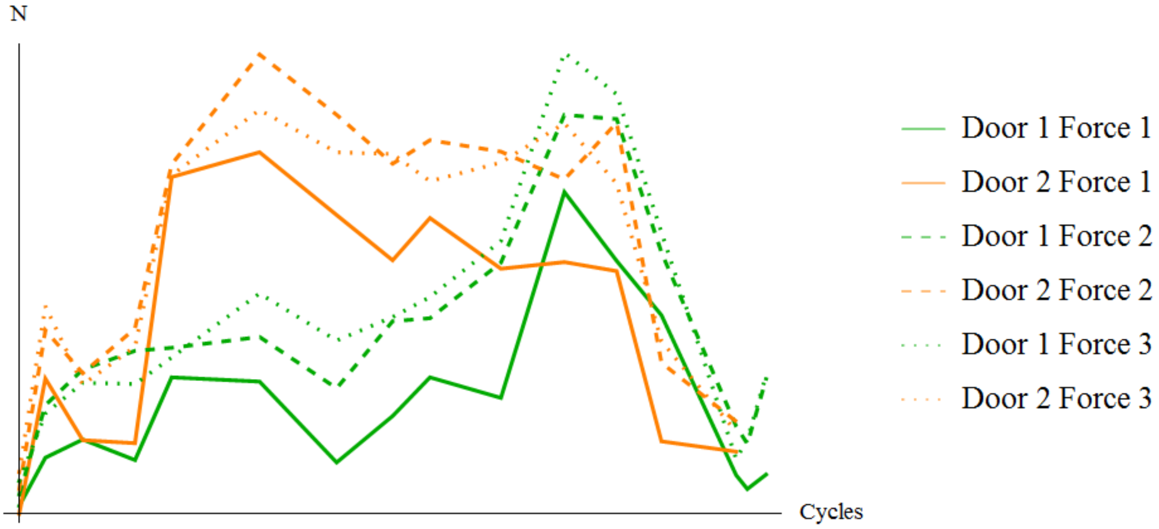
3.2. Analysis of the test procedure (APTA Step 1)

The tests within the case study “car door system” were performed in a climate chamber with the possibility of simulation of different temperatures and humidities. The mechanisms were tested in two separate and identically constructed testing facilities. Every test facility consists of two symmetrical doors which are driven by one power train. The symmetrical setup reflects the buildup of a car (left and right door). The power train opens and closes both doors within one test facility at the same time. Both test rigs (placed in the same climatic chamber) are driven separately. Every mechanism can be defined as one sample.

3.3. Definition of the life span variables and boundary conditions (APTA Step 2)

All mechanisms were tested under the influence of different boundary conditions (cf. table 1) which can be split into two groups. The first group (quantitative boundaries) is represented by seven combinations of different temperatures and humidity. The second one (qualitative boundaries) consist of eight factors with the objective of additional influence on the system (e.g. particles, additional stress or system adjustment). Particles simulate foreign objects and represent a typical, additional impact affecting the car door within the usage phase (e.g. sand or dust). Boundaries listed in the table 1 are anonymized and correspond to the real application conditions.

Figure 3: Force distribution of door 1 and 2



All doors were tested for several hundred thousand cycles. In the meantime, three forces and three displacements were measured within the mechanisms in irregular cycle intervals. The analyzed forces and displacements are attributes with an influence on the performance of the products in the whole product lifecycle. Due to the confidentiality of the data the accurate description of all functions of measured quantities as well as the testing program has to be disclaimed. Nevertheless it doesn’t have any influence on the reliability analysis of prototypes.

Every series of measurement consist of 16 gaging points. An example of the distribution of the points is shown in the figure 2 and 3 and represents the features of all measurements.
A plot of the force distribution along the whole measurement series for two doors with three forces each is illustrated in figure 2. Cycles are plotted on the abscissa and forces in newton in the ordinate. Colors of the lines differentiate between door 1 (green) and door 2 (orange). Line types characterize the different forces, whereas the same line types indicate the same forces in different doors. Hence the green and orange continuous lines represent the same forces of door 1 and 2 respectively. By the examination of the line profiles some similarities can be identified and shall be discussed.

A systematic offset of force 1 and the other ones can be observed in both cases. Force 2 and 3 in both doors are nearly congruent. All forces within every door show a very similar development which means a similar reaction of the technical system with regard to the test program. Thus, with respect to door 1 after a rather constant trend followed by an increase of the line occurs a fall into nearly the same level as at the beginning of the test. This means, that the system is recovered after the whole test cycle and the amount of force before and after the test is nearly the same.

Differences in the reactions of the door systems (e.g. trends) between the doors can be explained by the manual production and assembly and as an outcome of both of them the dispersion effects of the prototypes.

Figure 4: Displacement distribution of door 1 and 2

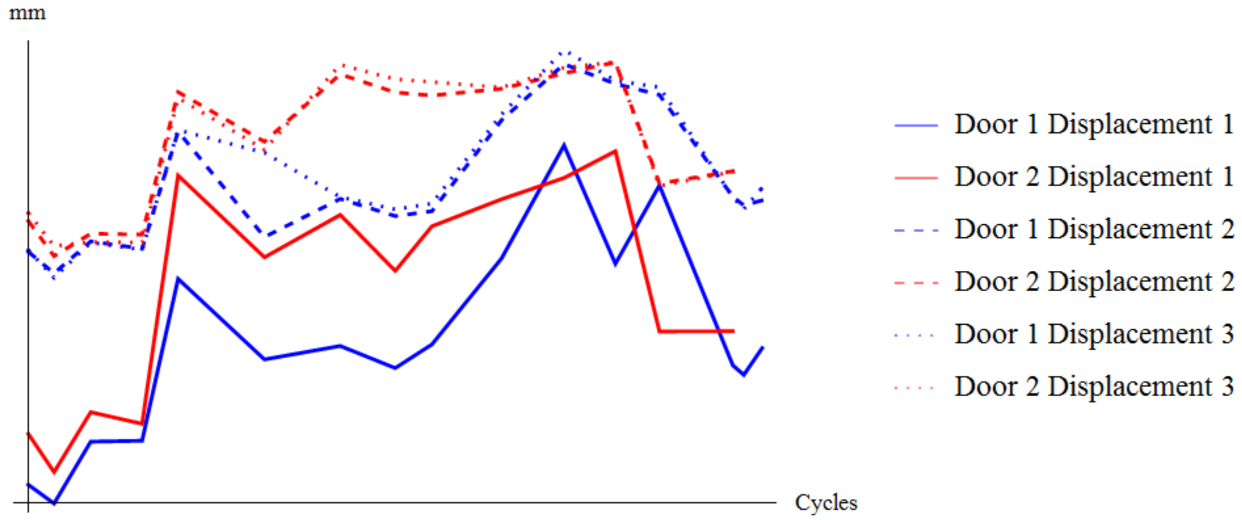


Figure 3 shows the displacement characteristics of the same doors as in figure 2. Door 1 is marked with the blue, door 2 with the red line. Line styles correspond to the figure 2. Cycles are plotted on the abscissa and displacements in millimeter in the ordinate. Systematic analysis of the lines distribution provides similar results (offset, congruence, development regarding the testing program) as in figure 2. Contrary to the force, after the whole test, the system doesn't recover in terms of the displacement, which means that the displacement at the end is remarkably higher than at the beginning.

A comparison of force and displacement yields a correlation in the trends for every single door. An increase of values followed by a constant distribution and a fall in door 2 as well as constant, increase, and fall distribution in door 1 show small differences in mechanisms and a similar reaction to the environment boundaries. This leads to the assumption of statistical similarities of the prototypes.

3.4. Statistical analysis of the test data (APTA Step 3)

Systematic analysis of the graphs provides many optical similarities (e.g. trends, peaks, offsets). In order to perform a statistical analysis of the test data all facts will be summarized. Overall there are 24 samples (three forces, three displacements in four doors) with 16 values available. In case of all doors the samples are statistically independent.
The statistical test of Shapiro-Wilk and Anderson-Darling [1] with the null (and alternative) hypothesis:

$$H_0 : F = F_0 \ (and \ H_1 : F \neq F_0 \ ) \tag{1}$$

The hypothesis that the sample data are normally distributed by a significance level of α=5% can't be rejected in case of all samples. Nevertheless the amount of the data within a sample as well as the number of prototypes stay at a low level, therefore - depending on the sample size - parametric and nonparametric test will be applied [2].

For the comparison of samples, different significance tests according to different applications are available. In this case nonparametric tests will be described. Parametric test were also undertaken and provide the same conclusions. The null (and alternative) hypothesis of Mann-Whitney U test [10]

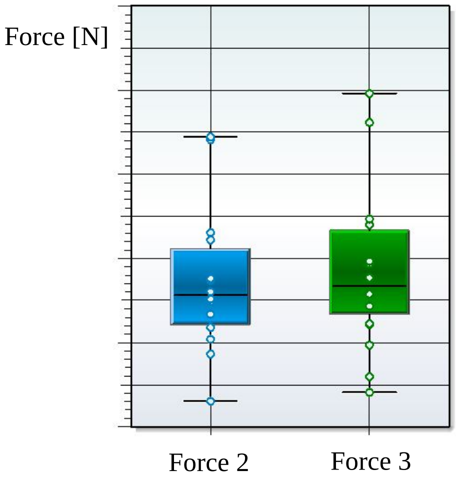
$$H_0 : F(z) = G(z) \; (and \; H_1 : F(z) \neq G(z - \theta) \,) \tag{2}$$

that the samples have the same focus and the null (and alternative) hypothesis of Levene's test [10]

$$H_0 : F(z) = G(z) \; (and \; H_1 : F(z) \neq G(\theta z) \,) \tag{3}$$

that the variances of the samples are equal weren't rejected in any case. Hence it can't be proved, that all forces and displacements are significantly different in terms of the focus and the variance. The same conclusions can be drawn by the analysis of the boxplots. An example is shown in figure 4 and demonstrates the comparison of force 2 (on the left) and force 3 (on the right) of prototype door 1.

Figure 5: Comparison of the samples (force 2, blue color; force 3, green color)



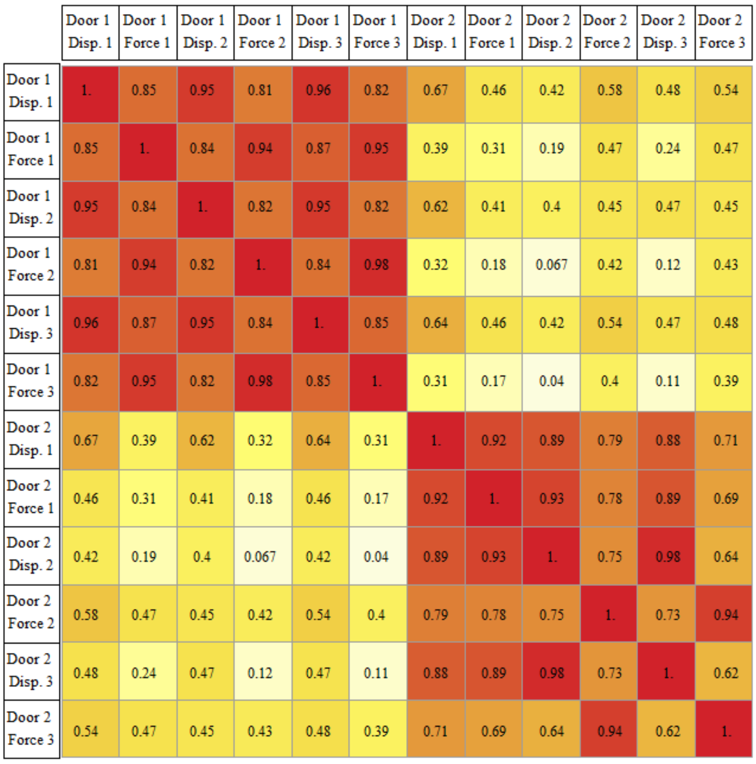
After application of the significance tests regarding the comparison of the focuses and variations of the samples, a regression analysis of all forces and displacements shall be executed. For the reason that the probes are normally distributed but the data volumes are small, the correlation analysis will be performed parametrically as well as nonparametrically.

Figure 5 shows the results of the correlation analysis with the assumption of normally distributed data with the use of Pearson's product-moment correlation coefficient [1]. In this case, all attributes of left door of both test facilities have been correlated with each other. The result of every single correlation is shown in the corresponding combination of the attributes in the matrix.

All Pearson coefficients within the first door are greater than 0.81, whereupon by a comparison of the same attributes (force with force and displacement with displacement), the coefficient increases to $r \geq 0.94$. In the second door the coefficients are slightly lower with $r_{min} = 0.62$. However by an analog comparison of the same characteristics the value increases to $r \geq 0.69$. In the case of both single doors it is a high correlation. Therefore, an assumption can be met, that the attributes of the mechanisms react in a similar way to the external influences. It is the same assumption as in case of the interpretation of values characteristics shown in figure 2 and 3.

The correlation of two separate doors (upper right and lower left corner of the correlation matrix) yields weak to very weak solution $(0.67 \leq r \leq 0.04)$. This can be traced back to the manual manufacture of the prototypes.

Figure 6: Pearson correlation matrix of the analyzed door prototype characteristics



	Door 1 Disp. 1	Door 1 Force 1	Door 1 Disp. 2	Door 1 Force 2	Door 1 Disp. 3	Door 1 Force 3	Door 2 Disp. 1	Door 2 Force 1	Door 2 Disp. 2	Door 2 Force 2	Door 2 Disp. 3	Door 2 Force 3
Door 1 Disp. 1	1.	0.85	0.95	0.81	0.96	0.82	0.67	0.46	0.42	0.58	0.48	0.54
Door 1 Force 1	0.85	1.	0.84	0.94	0.87	0.95	0.39	0.31	0.19	0.47	0.24	0.47
Door 1 Disp. 2	0.95	0.84	1.	0.82	0.95	0.82	0.62	0.41	0.4	0.45	0.47	0.45
Door 1 Force 2	0.81	0.94	0.82	1.	0.84	0.98	0.32	0.18	0.067	0.42	0.12	0.43
Door 1 Disp. 3	0.96	0.87	0.95	0.84	1.	0.85	0.64	0.46	0.42	0.54	0.47	0.48
Door 1 Force 3	0.82	0.95	0.82	0.98	0.85	1.	0.31	0.17	0.04	0.4	0.11	0.39
Door 2 Disp. 1	0.67	0.39	0.62	0.32	0.64	0.31	1.	0.92	0.89	0.79	0.88	0.71
Door 2 Force 1	0.46	0.31	0.41	0.18	0.46	0.17	0.92	1.	0.93	0.78	0.89	0.69
Door 2 Disp. 2	0.42	0.19	0.4	0.067	0.42	0.04	0.89	0.93	1.	0.75	0.98	0.64
Door 2 Force 2	0.58	0.47	0.45	0.42	0.54	0.4	0.79	0.78	0.75	1.	0.73	0.94
Door 2 Disp. 3	0.48	0.24	0.47	0.12	0.47	0.11	0.88	0.89	0.98	0.73	1.	0.62
Door 2 Force 3	0.54	0.47	0.45	0.43	0.48	0.39	0.71	0.69	0.64	0.94	0.62	1.

3.5. Evaluation of the test procedure (APTA Step 4)

According to the assumption of similar reaction of the mechanisms on external influences, the system with its boundary conditions can be mapped onto a mathematical system of equations, which can be easily solved. All external effects and changes of the mechanisms during the test phase have been defined as boundary conditions and are listed in table 1. Furthermore, an unknown has been allocated to every boundary condition. Between every measurement of the attributes the number and combination of the boundaries has been varied. The lowest number of driven cycles by given temperature and humidity was 500, in many cases multiples of it. Between two measurements multiple changes of the temperature occurred many times. By a definition of the variables the number of cycles was implemented with a factor of 1/1000. Hence 2000 cycles at temperature T2 correspond to the expression 2*x2. In addition to the variation of the temperature and humidity, the mechanisms were stressed with a set of boundary conditions which are not quantitatively measurable in terms of time and amount. Because of the fact that it is not possible to define how long the qualitative factors stress the mechanisms, their number of cycles were not considered and implemented by the definition of the equations. A realistic example provides a better understanding of the procedure. After the first measurement (m1) following steps have been performed:

- 1000 cycles at temperature T1
- 2000 cycles at temperature T4
- Application of particle 2
- Additional stress of the system
- 3000 cycles at temperature T7

Subsequently a second measurement (m2) took place. In this case 6000 cycles were performed between the two measurements. These steps can be described as follows:

$$m1 + 1 * x1 + 2 * x4 + x12 + x14 + 3 * x7 = m2 \tag{4}$$

and rearranged to:

$$x1 + 2 * x4 + 3 * x7 + x12 + x14 = m2 - m1 \quad (5)$$

All in all 16 measurements and 15 unknowns are available. With 16 values, 15 equations can be defined. Therefore the system of equations can be solved.

The interpretation of the results (cf. table 1) is shown by using an example of a measurement of one force and one displacement of the same door. The factors have no physical meaning and serve only the interpretation of the weighting of the influence of the boundary conditions on the system behavior. Following statements can be made (the notation Tx correspond to 1000 cycles at temperature x):

- T6 has the smallest and particle 3 the highest influence on both attributes
- T2 has the highest negative and T3 the highest positive impact on the system
- T3 has 10-times higher effect than T5
- T2 and T4 influence the force in contrary to all others temperatures negative
- T1, T3 and T5 influence the displacement in contrary to all others temperatures positive
- Particle 1 and particle 2 have, in contrast to particle 3, a negative impact on the mechanism
- System adjustment has the smallest effect out of all qualitative boundary conditions

Furthermore, the solution of this mathematical procedure allows a direct comparison of qualitative and quantitative boundary conditions.

3.6. Optimization of the test procedure (APTA Step 5)

Because of the low number of measurements and missing individual measurements (those after the application of every single boundary condition) it is not possible to verify the factors. Such a validation would not only confirm or reject the method but would also deliver new and important information (e.g. functional relationship between temperature and force/displacement or the size and shape of particle and force/displacement).

With the help of the factors it would be possible to provide a prognosis of the further performance of the system by a further development of the testing plan. This would reduce the amount of the measurements and costs.

Furthermore it is possible to define the most disadvantageous composite of the BCs (worst case scenario). An example for it would be the configuration of temperature T3 (x3), erasure of particle 1 (x10), system wash (x11) and particle 3 (x15). This compound would heavily (positively) influence the force and could exceed the limits prescribed by the requirements or could lead to system breakdown.

4. CONCLUSIONS

Development of technical complex products is affected by the challenge to identify and eliminate the potential weak points in early phases of product and components design. Here, the increasing complexity and functionality of the products are the key factors also because they can cause a wide range of failure spectrum. Accelerated tests offer the possibility to map the user behavior and, as its consequence, the potential expected failure spectrum over the load spectrum. The great challenge is the design of the test plans. The aim is to test the prototypes with regard to a wide failure spectrum in a short time and, as far as possible, with less test objects.

This paper presents on one hand the basic possibilities of prototype testing. On the other hand a case study with regard to a car door system outlines the statistical analysis of the test data based on small data volumes. The systematic application of nonparametric statistical models in combination with

parametric methods enables the comparison of the quality and reliability of the products and test facilities already in the early phases of the design phase.
Furthermore, the impacts of the simulated environmental effects on the prototypes can be described by a mathematical model which is the base of operations for further design of product improvement activities. A prediction of the expected life time by using the existing data is not possible, which is caused by the miscellaneous impacts of different markets (worst-case scenario). An adaption of the test plan for specific target markets would increase the significance of the statistical analysis and reliability.

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