Evaluation of Qualitative Accelerated Tests Practices in Product Development Process: A Computer Simulation

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Abstract — Reliability is an essential item for the product development phase, as it is from estimated values are obtained about how the product will behave and, consequently, about modes of design flaws and weaknesses. In short, these responses are important to offer to the market high quality products, in addition to providing safety to the customer. In this work, a product was proposed where its design was based on research on how its shape should be and three different raw materials were chosen to be applied to the product and, with the simulation, it was possible to discover the weaknesses and points of improvement and which material best suited the proposed product.

Key words — accelerated tests, computer-aided design simulation, product design, reliability.

I. INTRODUCTION

The market has become more exigent at the moment to buy a product in relation to its quality, because the capitalist economy has made consumers want products and services that are more attractive to their eyes, stimulating consumerism [1]. To maintain and strengthen consumer loyalty, it is essential that high quality products are delivered [2]. This fact has led companies to seek to satisfy and exceed consumer expectations by improving and controlling the quality of their product. In this way, the company will gain competitive advantage based on quality [3] which “is a key dimension of the market and competitiveness in capitalist societies” [1].

The quality of a product can be described in different ways; however, it can be explained in a categorized way, which are the dimensions of quality and, one of the main dimensions and which will be approached in this research, is reliability [3], [4].

Reliability is the probability that an item, product or system will operate under normal conditions for a period of time without fail [5]. Reliably became a dimension due to the present questioning and investigation, by the consumer, regarding the frequency of failures that a certain product will possibly have. Some complex products require occasional repairs to their systems, however, if the number of repairs is greater than conventional or expected, it means that the product is not reliable [3], thus, the market will tend not to purchase due to excessive expenses that they will have throughout the product life cycle.

Before launching a product on the market, it is important that its failure modes and reliability be identified. For that, a methodology called Accelerated Tests is used, whose objective is to accelerate the lifetime and stress a product, so that the potential failure modes and their respective frequency of occurrences are induced in a short period.

This research aims to design a product in which the qualitative accelerated testing practices are applied during its development process using computer simulation, the Autodesk Fusion 360 software, in order to get responses of the product’s failures, weakness and the best raw material, which will make the product in its most reliable design.

II. LITERATURE REVIEW

A. Product Design

For a product to have a rapid development process and being a profitable and successful product, its planning must be well structured. In addition, the concept of the product should be the best, well detailed and that several tests should be carried out before reaching mass production [6]. The lack of planning, when developing a product, leads to failures that increase development costs, production costs, many changes in product engineering and delay to deliver it to the market [7]. To avoid these costs, there are several reference models that serve as a guide to develop a product, and these must be adapted to the needs of each project. In general, the models in the literature are composed of stages where they are divided into gates or phases, that is, a gate or phase is only considered completed after the execution of all activities [8].

[7] shows a product development model divided into 7 stages with gates, which are: idea; pre-study; concept; development; preparation; production; sales. The model by [8] consists of 9 stages, which are: strategic product planning; project planning; informational project; conceptual project; detailed project; production preparation; product launch; monitoring the product/process; discontinue the product.

In short, the process of developing a product can be summarized in three macro steps, which are:

1. Planning: In this phase, you should have ideas of what the product will be and what is the problem of the market that will be solved. It must assess if there is technical and production capacity to develop a particular product [7]. Innovation is essential for the development of a new product; however, it requires investment and has risks. There are two
main types of innovation: radical innovation that generates something unprecedented (the success of the product is too uncertain, as there is no data that the market will, in fact, want the product) and incremental innovation that makes small changes in the concept or product technology [9].

2. Product Development: the technical specifications of the product must be defined; dimensions; tolerances; product performance; the quantity to be produced; material and the production process; manufacturing costs; the product architecture; the functions and structure of the product; the configuration of the product’s design or shape; product surface finish [10]. It is at this stage that tests and prototypes should be carried out [11]; In the early stages of the product development process, it is important to consider sustainability due to possible negative impacts that a product may cause on environment [12].

3. Manufacturing System Planning: It is time to define how the product will be manufactured. Production capacities and nowadays technologies to enable production must be considered. In addition, it is time to select and sequence processes in order to obtain lowest costs [11].

A strategy used to simplify the project and accelerate its development is to apply the principles of designing to produce and designing to assemble after the planning stages [13]. The design to assemble includes activities that guarantee the product assembly efficiency, such as functional analysis of components, analysis of fault elimination, analysis of component handling, analysis of component insertion. Designing to produce takes into account activities related to increasing product quality, in addition to geometric product specifications, material tolerance limits, QS-Stat and FMEA [7].

B. Reliability

Reliability is a function which allows predicting the operating time of a system by calculating the failure probability of its subsystems or components [14], [15], [16] mentions that reliability is an important property for all systems, as it allows to define how long an object can function during different operating conditions such as temperature, speed, loading and among others. Based on this, if a good analysis of the product’s reliability is performed, it is guaranteed that the components or systems will operate at the desired level during their life cycle [14], [17].

Safety and reliability are connected because the failure of a component or of a subsystem can lead the failure to a complete system and it may put in risk the consumer’s safety. Therefore, the low probability of failure and the long operation of a product are essential requirements in some products such as airplanes, for example [14], [17]. [18], [19] argue that the product must already be designed for reliability (Design for Reliability – DfR), as this focus will help in identifying prototype problems and will reduce the costs generated during the life cycle, failures in fields, besides reducing the time of arrival of the product in the market. The design of the product’s reliability is how to maintain the functions of a system without flaws in its life cycle. To contain these flaws that may exist, [17] affirm that one of the ways to predict the reliability of the product is by determining the reliability of its components, and then calculating as a whole. In addition, there is mathematical and statistical modeling of performance, simulations, tests and historical and product analyzes helps to determine system design flaws and potential failure modes that can occur under normal operational conditions. Changes in the design can be made to eliminate the flaws found and select the solution that best meets the reliability requirements [18], [19] and the product can proceed to the production phase.

A factor to be considered to create a reliable product is the manufacturing process. Reliable manufacturing processes are those that can produce products that meet design requirements efficiently, economically and firmly in bringing product specifications [20]. Therefore, one of the aspects to increase the reliability of a product is through the reliability of the manufacturing processes that must be thought out as thoroughly as the product design.

C. Accelerated Tests

Reliability tests are performed on a product and variables related to failures and performance parameters, which are affected by a particular operating condition, are collected for analysis of its life. Predict the reliability of a product during its development process, is an important factor, because it is possible to estimate the probability which it will performs its functions in a certain period with greater precision [21], [22].

The traditional method of evaluating the performance or failure time of a product is obtained through the analysis of a system, product or component in its normal operating condition [23]. Simulating the normal operating condition of a user ends up consuming many resources such as time and money, and this ends up not being advantageous to remain competitive in the market, in addition to that, it may even be impossible to obtain time data until failure in some products. In order to avoid these difficulties, the accelerated life test method emerged that allows to obtain, more quickly, the life characteristics, for example, Mean Time to Failure - MTTF and the failure modes present in a product [22].

This method is essential to estimate the product’s lifetime during the design phase, as it allows improvements to be made, that is, the positive effects of changes in the design that can reduce the frequency of failures or completely eliminate any identified failure [24]. It also reduces the period between the product’s planning and the time to launch it on the market. In addition, it helps to determine the warranty period and reduce its costs [22].

To apply the accelerated tests, some product samples must be tested under stress conditions above normal (these stresses can be temperature, vibration, voltage, etc.) so that they cause failures precipitously on the samples [22], [23]. With that, these tests must be selected properly in order to get accurate data about the product’s requirement, and they can be qualitative or quantitative:

- Qualitative: these are tests that, when properly applied, provide information about failures or failure modes that will occur during the life of the product and also about design weaknesses and possible product stress limits, when operated in normal conditions of use will be easily revealed [25]. It can be referred to the following names as Elephant tests, Torture tests, HALT, Shake & Bake tests. These tests are performed on small samples that are subject to a severe level of stress, multiple stresses, or time-varying stress (for example, temperature stress varies from hot to cold). If the sample
resists, it passed the tests, otherwise, actions must be directed so that improvements are applied to the product design so that the causes of failures are eliminated [23];

- Quantitative: tests that consist of quantifying the characteristics of a product's life under normal conditions of use and, thus, providing reliability information (such as failure rate and Mean Time Between Failures - MTBF) [25]. There are two quantitative methods of quantitative accelerated tests: Usage Rate Acceleration, which is used for products that do not operate continuously under normal conditions of use and, therefore, the product starts to operate continuously; Overstress Acceleration is already used for products that have very high or continuous use, the life test seeks to stimulate product failures by applying stress levels above the normal conditions of operation [23].

By identifying the tests that best suit the mechanisms and degradation factors present in a product, the life of the product will be accelerated [21]. In some cases, tests are carried out on several samples until all of them fail, which ends up consuming a lot of time, but also, tests can be carried out in a certain period or until a certain number of failures are reached. However, the most common way is to test samples operating in severe conditions continuously [24].

III. METHODOLOGY

The present work is an experimental research. The experimental processes occur when one or more variables are manipulated in order to cause impacts [26], and generate data. It was intended to evaluate the relevance of qualitative accelerated tests through the practices using computer simulation during the product development. Furthermore, it is characterized as a quantitative research. According to [26], this type of research aims to test theories based on the analysis of the relationship between variables. The data collected in the tests must be used in such a way that answers are found [27]. In this research the concepts of reliability, more specifically, the accelerated tests methodology was applied into a chosen product.

The experiments were made from computer simulation using the Autodesk’s software, Fusion 360. The product was designed according to the desired dimensions and specifications and then, three different materials were selected to compose the product. The variables related to qualitative tests were manipulated in order to obtain results regarding product design flaws and weaknesses.

IV. RESULTS AND DISCUSSIONS

A. Product Development Process

The product selected was a toothbrush holder. The closed toothbrush holder and closed toothbrush holder with ventilation for the allow the drying of the bristles to delay and, consequently, they stay moist. Moisture is a factor that facilitates contamination by harboring pathological agents for a longer period. In addition, closed holders allow contact between toothbrushes that enables the sharing of different contaminants. In short, it is scientifically proven that toothbrushes stored in airy environments have a smaller number of bacteria when compared to those stored in closed storages and closed storages with ventilation openings [28].

Based on this, the product was designed where water accumulation in brush bristles is avoided and direct contact between toothbrushes is also avoided. This device has the capacity to hold four toothbrushes. Having an area of 289.51 cm² and a volume of 103.606 cm³. Furthermore, as it is a simple product, the essential thing is that the material that composes the product has resistance to falls of 0.900 cm from the floor, as it is a measure of the standard height of a bathroom sink. The raw materials selected to compose the product were ABS plastic, acrylic and polypropylene.

The product drawings and their appearance with each selected raw material will be shown below:

![Fig. 2. Toothbrush holder – ABS plastic.](image1)

![Fig. 3. Toothbrush holder – Acrylic.](image2)

![Fig. 4. Toothbrush holder – Polypropylene.](image3)

B. Computer-aided Design Simulation

For each selected raw material, the software provided some physical properties about the product:
TABLE I: PROPERTIES OF THE PRODUCT WITH THE RESPECTIVE SELECTED RAW MATERIALS

| Material   | ABS Plastic | Acrylic | Polypropylene |
|------------|-------------|---------|---------------|
| Density (g/cm³) | 1.060    | 1.188   | 0.899         |
| Mass (g)   | 109.823    | 123.084 | 93.142        |

The tests used in the products were qualitative tests where a normal force was applied in three determined places, characterizing a static stress.

![Fig. 5. Places of stress application: A, B and C.](image)

To better understand the behavior of the product, three levels of stresses were applied that are above normal conditions of use. When a given force is applied to a surface, it deforms and pushes the body that applied the force. The three levels of force applied on the product were 98N, 300N and 600N.

Based on the strength generated by these masses, the software provided a very important data, which is the Safety Factor. This factor has a limit range from 0 to 15, where 0 means that the design is very poor, the value of 3.4 is considered the minimum value that a design can achieve and withstand the stress conditions applied and 15 is excellent.

This data shows a general result about how well a product is suited to a given stress condition. This item is calculated from the strength of the material by the applied stress.

![Fig. 6. Limits of the Safety Factor.](image)

C. Data Analysis

In order to analyze the data in general, the Min. Safety Factor data for each load of force applied by raw material was stratified to facilitate the visualization of the product's behavior in different materials.

At location A, ABS plastic presented the worst behavior in relation to stress and, secondly, there is Polypropylene (Fig. 7).

![Fig. 7. Min. Safety Factor behavior chart for each material at location A of force application.](image)

For the application of stress at location B, the product performed well due to the design of the area allowing greater support to receive external forces (Fig. 8).

![Fig. 8. Min. Safety Factor behavior chart for each material at location B of force application.](image)

Region C behaves as an area less tolerable to stress (Fig. 9), since the application of the first stress level (the 98N force) has already reduced the Min Safety Factor in ABS Plastic as in B already showed that the design for these areas is safer. As the stress level increases, for all types of materials, the design of region C had its safety factor reduced. Even so, the Acrylic showed the best behavior, and it is not expected to break.

![Fig. 9. Min. Safety Factor behavior chart for each material at location B of force application.](image)

In average, the material that presented the worst behavior in relation to extreme stress conditions was ABS Plastic (Fig. 10).

![Fig. 10. Min. Safety Factor behavior chart for each material at location B of force application.](image)
V. CONCLUSIONS

The use of the simplest CAD software can make relevant data available with easiness, which eliminates many costs related to prototype tests that could be carried out physically with the product. The use of computer simulation will reveal the weaknesses, limits, and recommendations for a product, such as the results based on the Safety Factor, which is automatically calculated by Fusion 360. This type of technology together with the concepts of reliability streamlines the process of to develop an excellent design at low costs and it is known that to maintain competitiveness in the current market it is necessary to offer the highest quality products and also offer maximum consumer safety.

In the present research, it was possible to explore in detail the weaknesses of the design, break points, levels of deformation, product limits in relation to the type of stress chosen in which it was chosen based on the literature on qualitative tests of reliability. The freedom to manipulate the variables allowed to identify which raw material would behave better to the chosen design, which, according to the results, was Acrylic since it presented a higher Safety Factor average in relation to the other raw materials selected to this work. In general, the data generated by the simulation clearly showed the points of improvement for the proposed product, and this is extremely important for reliability projects because it speeds up the validation process of a product with an excellent design to be launched to the market.

For future works, it is possible to elaborate more appropriately structured designs and test them using multiple stress tests, with time variables, free fall and among others to know more the probabilistic part of a product’s reliability.

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