RELIABILITY ENGINEERING TECHNIQUES FOR CONSUMER PRODUCTS

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ABSTRACT
Consumer products have been thought of as being low priced and unreliable. We will look at some of the best approaches to use in designing and manufacturing consumer products in regard to reliability, and how these approaches can result in improved profitability without increasing cost, and some aspects of implementing these approaches. The approaches discussed here can be adapted to the special needs of small companies and startups.

The intended audience here is the reliability engineer or technical manager in a small company or startup, involved in hardware product development for the consumer market. This material is aimed at those people or companies who actively care to make their products better and are willing to consider various approaches that may be within their budget.

Many of the techniques involved with making consumer products more reliable are common to reliability tools used for higher end products of any quality level or cost level. Analytical tools, such as FMEA (Failure Mode Effects Analysis), or HALT (Highly Accelerated Life Testing) are very useful for improving the reliability of consumer products.

In this paper, we will look at some aspects of how consumer products differ from industrial products, and what special concerns there are with product reliability; we'll discuss Strengths, Weaknesses, Opportunities and Threats (SWOT) and how they relate to consumer products reliability. We will discuss how reliability tools and methods for consumer products differ from higher end products, what tools are practical, and how some other aspects of consumer product quality and reliability differ. The special needs of the small company or startup will be considered, showing what reliability methods are more practical.

Key words: consumer product, product reliability, reliability test, product failure, product safety, HALT, FMEA

INTRODUCTION
Consumer products have been thought of as being low priced and unreliable; they may be considered disposable, not repairable, and come with expectations of failure; certainly this was and is true in many low end products. We will look at some of the best approaches to use in designing and manufacturing consumer products in regard to reliability, and how these approaches can result in improved profitability without increasing cost, and some aspects of implementing these approaches in ways that do not add cost or slow the project down. The approaches discussed here can be adapted to the special needs of small companies and startup companies. The tools of reliability can be applied to consumer products, with the benefit of supporting a rapid time-to-market, reducing the overall cost to project development costs, and reducing the unfavorable impacts of product failure in the field. Appropriate use of reliability engineering methods can make for more reliable consumer products which strengthen the company's position in the marketplace, whether that company is a large established firm, or a startup.

Many of the techniques involved with making consumer products more reliable are common to reliability tools used in any product and any quality level or cost level. Strategies for consumer product reliability development are common to all products, and include earlier assessment of reliability issues, use of design for reliability methods and tools, prototype evaluation, testing, and teardown analysis. Many of these tools are straightforward, and do not require numerous samples or expensive equipment. With consumer products, it is sometimes thought that a few defects are acceptable. However, with the consumer reviews on the Internet, bad news travels fast. And in the case of children's toys, while some might think that the reliability of the toy is not important, a toy that suffers from reliability problems may become broken and present a safety hazard or if it fails, it is a DOA (Dead On Arrival), directly impacting the profitability of the manufacturer. Toys with small parts, or toys in which parts can break away represent choking hazards; deaths due to choking are reported annually by the CPSC [1]. Safety of toys is addressed in ASTM F963 Standard for Toy Safety [2], and numerous other related toy safety standards. Safety is a prime concern in all consumer products, and is often tied in with product reliability.

HIGH LEVELS OF PRODUCT RETURNS WITH NO FAULT FOUND

With retail products, there are high levels of product returns, many of which are probably not defective. These so-call NFFs (No Fault Founds) reflect a large return industry. Product returns can be due to a variety of factors. "Buyer's remorse" refers to the end buyer who, for whatever reason, doesn't want the product, even though it is not defective, and returns it to the store. It may be because they cannot make it work, or the product is not really what they expected, or it was the wrong color. Perhaps they just wanted to try it out, and after trying it out, they are done with the trial and decided to return it. Some users do not know how to setup and use the product; in one portable product (i.e., ran on batteries), there were a number of returns with complaints indicating that the product did not operate, yet the battery was still in its sealed package. So it is clear that with consumer products, there is a need to have clear product information on the packaging, and with easy to follow instructions for installing and setting up the product.

The manufacturer in consumer products often carries the burden of product returns whether those products are truly nonfunctional, or merely suffer from buyer's remorse. Estimates of the percentage of returns vary widely from various sources. Accenture estimates that manufacturers spend about 5% to 6% of revenues to manage all aspects of customer returns, including receiving, assessment, repair, reboxing and restocking [3]. They estimate that at the retailers, returns represent 2% to 3% of sales; and that for electronics, of the returns, 68% are "no trouble found", 27% are associated with "buyer's remorse" and 5% are defective.

SquareTrade is a provider of device protection & warranty services for electronic consumer products. They analyze product returns and so publish actual failure data. In 2009, they reported that 31% of laptops experienced some form of failure [4]. This year they reported that Apple iPhone owners have spent $14 billion to repair and replace their iPhones since 2007 [5].

So while the percentages of actual defectives as a percentage of the returns is not that high, the costs of repair and replacement are large. Add to this the frustration levels of end users, and the negative customer comments broadcast widely on the internet.

Figure 1. Breakdown of returns costs, according to Accenture research [3]

In the consideration for higher-end consumer products, such as smart phones or more higher-priced audio equipment, headsets, interconnect cables, computer accessories, the consequences of reliability issues can result in nonfunctional products being returned as DOA. For the small company or startup, these returns can have a serious impact on the viability of the company.

In this paper, we will look at first a review of the basics of reliability as it applies to consumer products, and some of the common misconceptions about this. And then we will look at some more realistic approaches to implementing a more reliable design, and aspects of manufacturing that affect product reliability. Examples will be given of simple steps that have been taken to improve the reliability of a product or the production process.

Start up companies, such as crowd-funded companies are under pressure to launch their product as soon as possible; time-to-market is key to market penetration. In the rush to build and ship product, concerns about verifying product reliability and quality are often set aside. Cash is a precious resource; often times the first production build is financed through prepaid sales. We will look at what reliability tools can be modified to meet some of their needs and help insure product reliability.

One of the benefits of implementing higher reliability into consumer products is the reduction in environmental waste. So for each improvement on product life there is a multiplier effect on the amount of waste generated in manufacturing, reduction in DOA's, and the reduction in waste and disposal at the end of product life.

IMPROVED RELIABILITY MAY LEAD TO SOME REDUCTION IN REPLACEMENT SALES

Analysts have commented reduced sales at two of the major smartphone suppliers, Apple and Samsung. Longer lasting phones have a lower impact on the environment, and there is some reduction in sales [13].

Smartphone markets are slowing because they have served their purpose; sales will experience growth as the companies introduce upgrades (in Apps, or with the introduction of 5G devices) [14]. In this author's opinion, the higher reliability of the products serves as an example for other consumer product manufacturers, demonstrating that higher reliability can help the company improve market share.

RELIABILITY CONSIDERATIONS OF CONSUMER PRODUCTS IN SMALL COMPANIES OR STARTUPS

Is it even possible to have reliable consumer products? In a recent SMTA webinar [6], Craig Hillman of DFR Solutions presents several examples of consumer products with high reliability, and shares his views of how to achieve that reliability. One example discussed is the iPad2 which has demonstrated extremely high reliability, according to statistics from SquareTrade, the consumer product insurance survey report. Another example given are antilock brake modules, which have demonstrated very low failure rates, based on industry statistics. Part of the emphasis in the webinar suggests that teams should work to solve problems, rather than over analyze or study them. Engineers are expensive and they should focus on success. Focus on time-to-market and the manufacturing process, rather than intensive failure analysis. One major cell-phone manufacturer places a lot of control over their supply chain; they may own the equipment, develop the process recipe, and specify the material sources. They focus less on post-process evaluation.

Companies typically focus on rapid product development, cash preservation is key in small company. For a new technology or a new market, time to market is key to establishing market share, and concerns for reliability may be less.

The methodology for implementing higher product reliability in a startup company or a small company is basically very similar to that used in any size company except that there is more focus on rapid assessment, and time-to-market. A number of the reliability tools can be utilized, especially activities that do not cost a lot. This would include review of designs, FMEA, stress analysis of circuits, and testing of critical parameters. While HALT can seem expensive, it is certainly a fast and reasonably priced method for identifying operating limits and failure modes, and providing keys to understanding and improving product reliability. While small companies may think that reliability and product quality is not essential, they need to realize that DOA's and product failures can result in bad reputations, high returns, and possibly even product liability issues.

In a small startup company or startup, the project often takes a leap from engineering prototypes into early production. While this may not be desirable from a reliability point of view, it is certainly common. Another concern is that many companies think that by outsourcing to a design house and certainly to a contract manufacturer, they are avoiding having to deal with the various challenges of product qualification, quality control, and product reliability verification. Small companies should become very involved in the design verification, preparation for quality control, and reliability verification steps, even if they are not directly controlling all this. Using contract manufacturing, and outsourcing methods do not guarantee adequate quality control. But it may be the only practical approach that a small firm can utilize. In any event, the key engineer responsible for product quality and reliability should if at all possible visit the contract manufacturer, and become involved in reviewing failure data, failure analysis and other quality control statistics. Several key aspects of reliability in a startup or small company are that first, while it may seem tempting to jump from engineering prototype into mass production, strategic thinking should be put into what additional qualification steps and design for reliability verification steps are being left out. It may be possible to identify the impact of these this approach and be on the lookout for possible consequences. Many of the venture backed accelerator programs have developed intensive startup boot camps [7], with focus on crowd funding, rapid product development, and marketing. The efforts for product reliability need to support this rapid time-to-market approach, with careful planning, rapid execution of reliability test plans, and timely reports and decision making.

SWOT ANALYSIS AS REGARDING CONSUMER PRODUCT RELIABILITY

Let us consider reliability of consumer products from the small company or startup, in regards to a SWOT analysis: Strength, Weaknesses, Opportunities and Threats, and how product reliability fits into that discussion.

Strengths: A key strength of a small company or startup is that they typically are able to move faster, or change their strategy. They can respond quickly to a shift in the marketplace, resolving a product problem, respond to an increase or decrease in product demand, and other market forces. During the reliability analysis or testing of their product in the early project phases, if there are problems found at least, they are more able to change the design or shift their product focus, more so than a larger company.

Weakness: A weakness or challenge facing the small company or startup, is that there are few resources internally to draw from. The company may need to

preserve cash so much that the project team cannot afford a larger number of prototypes, or reliability test equipment. So for example if they need special chambers for reliability testing, they typically would rent time in a local lab. If they need reliability skills not represented in the group, they would either hire someone or find a consultant.

Opportunities: while the expectation that a consumer product is cheap or unreliable presents a challenge, it also presents the opportunity to prove how good the product is. If a consumer product has shown to be reliable, easy-to-use, popular, that certainly presents an opportunity for success. Consumer products are built in such volume that if the process and the product design are done right, they really can establish a reputation for quality, reliability and good performance. Examples include wireless charging, used in electric toothbrushes and now used in smart phones, the success of music player earbuds which have excellent audio and product ruggedness at a reasonable price, and many others.

Threats: A threat facing the small company is the perception, right or wrong, that consumer products are cheap, easy to break, and not repairable. This not only sets expectations for a certain type of product reliability, it also sets expectations on pricing. The company's product may actually be more reliable or have a lower total cost of ownership than a competitive product but the consumer product marketplace is typically driven by price. These pricing pressures may result in design decisions being made, that reduce the product reliability. A key requirement for reliability of a consumer product is that it performs well and does not fail when introduced in the marketplace. Bad news spreads fast In today's internet-based product reviews. A product that encounters a problem or failure is targeted for abusive comments on the internet, whether deserved or not. This is true more so for startups and small companies, compared to suppliers of capital equipment. Another serious threat to the myriad of IoT (Internet of Things) products coming out is the threat of viruses and cyber crime; the IoT Institute recently published predictions on IoT Security in 2018 [8], stating that many cybersecurity professionals expect successful attacks in the next year. The area of IoT security poses multiple threats to the consumer product industry. While this may not appear to be an issue for product hardware reliability, it directly impacts product success in the marketplace; also, note that many product returns and customer complaints go undiagnosed, and the interaction between viruses and hardware failures may be difficult to determine without careful analysis.

Technology strategy: there In project development there are two strategies for the inclusion of new technologies into product design: revolutionary strategies are used to develop products based on completely new strategies, new technologies and other significant changes in either the marketplace or technology product lineup. The alternate approaches is the more evolutionary strategy where less significant changes are introduced for each new model lineup, or change to the market strategy, or other parameter; this evolutionary approach to new product design is safer, and therefore likely to result in more reliable products; it is used often by larger, more cautious firms. By its nature, the revolutionary strategies have higher risk, and the fallout in the marketplace is greater, and there are probably more reliability issues.

Manufacturing strategy and component sourcing both have heavy influence on the reliability and quality of consumer products. Often the design firm may not have its own manufacturing facility, and will use the services of a Contract Manufacturer (CM). While this certainly makes their burden less, they cannot relegate the control of the product design, quality, and reliability to the CM and component suppliers. While it's not practical to control every aspect of each manufacturing and sourcing supplier, it's important to document the quality and reliability expectations. The small company or startup should evaluate candidate CMs in regards to the CMs understanding and commitment to product quality and reliability. This authors experience is that good CMs have understanding of product quality - methods of inspection, statistical process control (SPC) and fixing problems, but often lack understanding of product reliability - what it means or how to assess for reliability or how to conduct reliability testing. While the small company cannot remotely control the CMs detailed methods for controlling product quality and reliability, they should monitor process statistics and product quality carefully through testing, failure analysis and root cause correction. Supplier selection and quality should be monitored for critical components.

PROJECT MANAGEMENT PHASES AND CONSUMER PRODUCTS

Reliability tools and methods are used in each of the project phases that are examined include the following; each will be discussed as to special steps or methods for consumer products:

* Concept Phase - benchmarking and review of reliability goals.
* Design Phase: reliability modeling, FMEA (Failure Modes Effects Analysis), human factors analysis, cost review and reduction.
* Prototype Phase: HALT (Highly Accelerated Life Test), ALT (Accelerated Life Testing), user testing, lifecycle testing, cost reduction.

* Manufacturing prototype phase: fixturing, Process FMEA, HASS (Highly Accelerated Stress Screening), cost reduction.
* Full-scale production: transition to HASA (Highly Accelerated Stress Auditing), cost improvement.
* End of life: environmental impact, recycling.

Phase		Activities	Tools
Concept		Define HW reliability requirements	♦Benchmarking ♦Internal Goal Setting ♦Gap Analysis
Design	Architecture & High Level Design	Modeling & Predictions	♦Reliability Modeling ♦HW Failure Predictive Analysis (FMEA & FTA) ♦HW Fault Tolerance ♦Human Factors Analysis
	Low Level Design	Reliability Analysis	♦Human Factors Analysis ♦Derating Analysis ♦Worst Case Analysis
Prototype (first time product is tested)		Detect design defects	♦HALT ♦ALT ♦DOE ♦Multi-variant Testing
Manufacturing		Identify and correct manufacturing process issues	♦RDT ♦HASS ♦HASA
Operations and Maintenance		Continuous assessment of HW reliability	♦ORT

Figure 2. Reliability Tools for Project Phases

Not that cost reduction is listed in most of the project phases; while cost reduction might impact product reliability negatively, it is an important project goal and so is listed. Cost reduction changes do not need to impact reliability unfavorably, if evaluation is carried out methodically. Sometimes design features are removed or reduced as part of a cost reduction, and this may result in simplified operation and simplified designs with the effect of improved reliability. An example the electric toothbrush is the elimination of exposed charging contacts with inductive charging, which is safer and more reliable. this trend is now appearing in smart phone charging stations at the various espresso coffee bars. The elimination of exposed charging contacts is a improvement in the reliability of the product. In some smart phones, making the batteries inaccessible to the end user likely reduces the cost of the product, and being simpler may be more reliable.

In each of the project phases, we'll look at how traditional reliability engineering techniques may be modified for consumer products or for a fast-paced startup company. Companies often don't want to spend large sums on equipment, or and do not have the patience for the long-term life testing.

Concept Phase: product concepts are developed. This might include benchmarking and review of reliability goals. During the concept phase, decisions are made about the technology strategy. This is where the planning decisions are made as to whether to investigate and seek new technologies, or new market strategies versus taking a more evolutionary approach, that is, taking moderate steps to advance the technology or market strategy. The more conservative approach of an evolution of technology would likely result in higher product reliability, but may have significantly less market appeal. With consumer products, there is often a tendency to add some features into the new product version without a major change in product technology.

Design Phase: analytical reliability tools can be used during this phase, such as reliability modeling (Predictions, MTBF), FMEA, human factors analysis, tear down analysis. Tear down analysis will identify issues with manufacturability and component assembly, workmanship, usability, and cosmetic. FEA (Finite Element Analysis) can be used to analyze the mechanical strengths of the product, and its ability to survive the drop test. When electrical schematics are available, electronic stress analysis and derating can be performed, as well as a design FMEA. These tools are fairly straightforward, and do not cost a lot and can be done typically without physical samples. Many of the tools can be performed without detailed documentation. Refer to references for more discussion of the tools and methods used in reliability engineering [9], [10].

Prototype Phase: reliability tools include HALT, ALT, user testing, mechanical life cycle testing. The reliability program can speed time to market, program cost. During the prototype phase, there are a limited number of samples available which are representative of the product design, but may not have been produced using manufacturing tooling or methods. Depending on the construction of the product, this may be a good time to perform HALT testing, mechanical lifecycle testing, and possibly some of the environmental tests or accelerated life testing; refer to [11], [12] for a discussion of HALT. It is during this phase that there is typically the most activity of reliability testing. HALT is a quick way to discover product operating and destruct limits through the use of high stresses; when coupled with failure analysis and corrective action, it can offer a method to significantly increase the product reliability. It has been used with success on consumer products by companies that are committed to product quality and reliability. During the reliability analysis and testing, a number of failure modes may be uncovered. Figure 3 is a table of typical failure modes discovered during reliability test program.

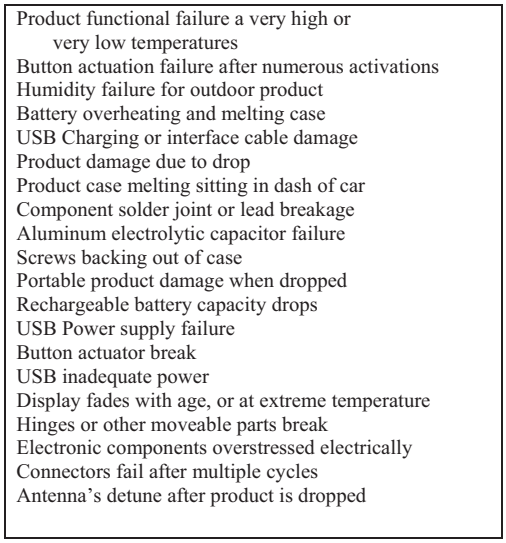

Figure 3. Typical Consumer Product Failures Discovered During Reliability Test

Manufacturing prototype phase: fixturing, Process FMEA, HASS. During the manufacturing prototype phase, the assembly and test fixtures are built and verified, and production standards set for unit labor times, etc. This is probably the last chance to introduce product design changes or minor tooling changes so as to improve product reliability. Typically with consumer products, there are no major design changes made after release to manufacturing. If a major design changes needed it is sometimes introduced during the next model revision. HASS is a manufacturing version of HALT, and has been used successfully for products that have higher customer expectations of reliability and quality.

Full-scale production: with the release to full-scale production, the primary focus is on improving manufacturing yields and quality control, through the use of statistical process control charts. Again, there are generally few opportunities for design improvements so as to improve product reliability. If HASS is used as a screening tool, then during the full-scale production phase would be the time to start planning for an audit version of HASS, which is HASA, (Highly Accelerated Screening Audit).

End of life: environmental impact, recycling. Returns of consumer products have a tremendous impact on landfill in the environment. With the high number of no-fault founds, and the difficulty of refurbishing products, the impact of packaging and product into the landfills is significant. Anything that can be done to reduce the returns will have a favorable effect on the environment.

SUMMARY

This discussion has looked at the reliability of consumer products, and how reliability tools and methods can contribute to the project goals of fast time-to-market, and improved product life. Consideration is given for the pressures in the small company or startup, with cash limitations; reliability tools are identified that have little or reasonable costs, but higher value in improving product reliability. SWOT analysis is given, looking at the contribution of reliability methods involved when considering the product Strengths, Weaknesses, Opportunities and Threats, in consideration of product reliability. Finally, reliability tools are discussed for each phase of the project development cycle.

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