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Reliability and its Economic Significance in Electronic Equipment

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Abstract
The importance of reliability in almost all areas of human endeavors cannot be over emphasized. The concept of reliability is synonymous with quality of goods and services. This Paper evaluates key parameters of reliability, the importance of reliability predictions, as well as how reliability can be improved by the application of redundancy. Various factors affecting reliability were also considered. It was also observed that reliability predictions in electronics equipment should be paramount in the heart of a design engineer. Reliability is very important in various ways like risk analysis, environmental protection, quality control, optimization of maintenance and operation of equipment and most importantly Reliability is considered as quality of products in engineering designs.

Keywords: Reliability, Reparability, Maintainability, Redundancy, Availability, Failure rate (λ), MTBF, MTTF,

Introduction
Reliability could be defined as the probability that a piece of equipment operating under specified conditions shall perform satisfactorily for a given period of time. Reliability is a probability having a value between 0 and 1. A prediction of reliability is an important element in the process of selecting equipment for use by electronics equipment providers and other buyers. It is essential during the design stage of engineering systems life cycle. Reliability is a measure of the frequency of equipment failures as a function of time. Reliability has a major impact on maintenance and repair costs and on the continuity of service. Electronic products introduced to the market have to fulfill specific quality criteria. There are differences in customer's expectations depending on the product type and application and reliability plays an important role in winning customers' confidence.
Commercial aircraft are required to have multiple redundant computing systems, hydraulic systems, and propulsion systems so that a single in-flight equipment failure will not cause loss of life. A more recent outcome of the importance of reliability is the Internet, which relies on a backbone of routers that provide the ability to automatically re-route communication without human intervention when failures occur. Satellites placed into orbit around the earth must include massive active redundancy to ensure operation will continue for a decade or longer despite failures that may occur to various parts. These facts prove that redundancy increases reliability. This paper briefly explained the concept of reliability and its economic importance to electronic equipment design.

Related Works
The IEEE defines reliability as the ability of an item to perform a required function under stated conditions for a stated period of time [2]. In this context, an item can be any system or product, e.g. a mobile phone, an integrated power amplifier, or an airbag system. For the discussion on reliability a specification that defines good and failed devices is required. Specifications have to include tolerances; therefore, a changing device parameter does not automatically imply a failure. They also have to include the allowed operating conditions, including circuitry and environmental impacts. The IEEE definition also includes the factor time, highlighting its importance when talking about reliable or unreliable components.

However, not only the operating time but also the storage time for devices on stock has to be considered. This is on one hand important for components which are not permanently used and wear out therefore cannot be monitored, and, on the other hand, for articles that are kept on stock for long periods. This is especially the case for spare parts.

Product reliability is quantified as Mean Time Between Failure (MTBF) for a repairable product and Mean Time To Failure (MTTF) for non-repairable product [2]. [8] Ross (2010) considered two components in standby configuration. Component 1 is the active component with a Weibull failure distribution (beta=1.5, eta=1000). Component 2 is the standby component. When Component 2 is operating, it has a Weibull failure distribution with beta=1.5 and eta=1000. Note: Even though Components 1 and 2 have the same distribution and parameters, it is possible that the two can be different. For the quiescent distribution, consider three different scenarios:

1. Same distribution as when in operation (hot standby).
2. beta=1.5, eta=2000 (warm standby).
3. Cannot fail in quiescent mode (cold standby).

To calculate the system reliability at 1000 hours one will only consider the non-repairable case, i.e. when a component fails, it is not repaired/replaced.

The reliability of the system at some time, t, can be calculated using the following equation:

$$R(t)=R_1(t)+\int_0^t f_1(x)\cdot R_{2,sb}(x)\cdot\frac{R_{2,A}(t_e+t-x)}{R_{2,A}(t_e)}dx \quad (1)$$

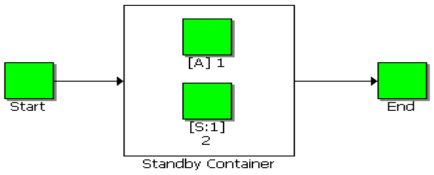
where,

- R_1 is the reliability of the active component
- f_1 is the pdf of the active component
- $R_{2,sb}$ is the reliability of the standby component when in standby mode (quiescent reliability)
- $R_{2,A}$ is the reliability of the standby component when in active mode
- t_e is the equivalent operating time for the standby unit if it had been operating at an active mode, such that:

$$R_{2,sb}(x)=R_{2,A}(t_e) \quad (2)$$

Solving Eqn. (2) with respect to t_e, you can obtain an expression for the equivalent time, which can then be substituted into Eqn. (1).

The following figure illustrates the reliability block diagram (RBD) for the system



The Start and End blocks have no failure information (*i.e.* reliability of 100%) and therefore do not affect the reliability of the system. The active and standby blocks are within a Standby Container, which is used to specify standby redundancy.

Electronic components have a wide range of failure modes. These can be classified in various ways. [4] Shows that Failures most commonly occur near the beginning and near the ending of the lifetime of the parts, resulting in the bathtub curve graph of failure rates. Burn-in procedures are used to detect early failures. In semiconductor devices, parasitic structures, irrelevant for normal operation, become important in the context of failures; they can be both a source and protection against failure. [5] Proves that applications such as aerospace systems, life support systems, telecommunications, railway signals, and computers use great numbers of individual electronic components. Analysis of the statistical properties of failures can give guidance in designs to establish a given level of reliability. For example, power-handling ability of a resistor may be greatly debated when applied in high-altitude aircraft to obtain adequate service life. A sudden fail-open fault can cause multiple secondary failures if it is fast and the circuit contains an inductance. This can cause large voltage spikes, which may exceed 500 volts. A broken metallisation on a chip may thus cause secondary overvoltage damage. Thermal runaway can cause sudden failures including melting, fire or explosions[9].

Analytical Approach (Methodology)

Brief History of Reliability

Beginning from the early stages of the industrialization of electricity, reliability was and still is a major concern. It is also often a show-stopper for the introduction of new technologies. Looking back in history, it required nearly 70 years until the reliability of the incandescent light bulb was high enough to make electrical lighting commercially interesting. Engineers had put much effort into finding materials used for the filament as well as for the gas surrounding it. Further technological advances finally offered high-performance vacuum pumps. This made the fabrication of the evacuated bulbs possible, which finally became even more successful. These shows that reliability is important for new products and that the two key issues for the development of reliable products are materials and technology.

Key Parameters of Reliability

Systems are often required to be available and working for a certain amount of time during their lifetime. Manufacturers or service operators have to guarantee their customers that a given device or infrastructure operates at least for a specific time per month/year. This implies that the system can be repaired and maintainability is given. Failed systems can therefore be restored to working condition by repairing or changing parts. However, for a single semiconductor device, maintainability is not given, since failures cannot be repaired. Hence, in reliability engineering the term serviceability is used for systems that cannot be repaired. This is also used when a repair is not an option. This is true for cheap products, e.g. inkjet printing cartridges, or for products where once set in operation, repair is impossible, for example, due to inaccessibility.

Every product has a failure rate (say λ) which is the number of units failing per unit time. This failure rate changes throughout the life of the product. There is what we called mean operating time between failures (MTBF) which applies to equipment that is going to be repaired and returned to service, and mean time to failure (MTTF) which applies to parts that will be thrown away on failing.

In engineering reliability emphasizes dependability in the lifecycle management of a product. Dependability or reliability describes the ability of a system or component to function under stated conditions for a specified period of time. Reliability may also describe the ability to function at a specified moment or interval of time (Availability). Reliability engineering represents a sub-discipline within systems engineering. Reliability is theoretically defined as the probability of success, or as the frequency of failures, or in terms of availability, as a probability derived from reliability, testability and maintainability. Testability, Maintainability and maintenan ce are often defined as a part of "reliability engineering". Reliability engineering deals with the estimation, prevention and management of high levels of "lifetime" engineering uncertainty and risks of failure.

The Bathtub Curve

The statistical distribution of failures can be visualized using the hazard curve. This curve shows the devices failure rate, also known as hazard rate, over the operating time. The widely accepted typical shape of the hazard curve is the bathtub curve shown in Fig3.1 below. This curve is originally derived from the life expectations of humans.

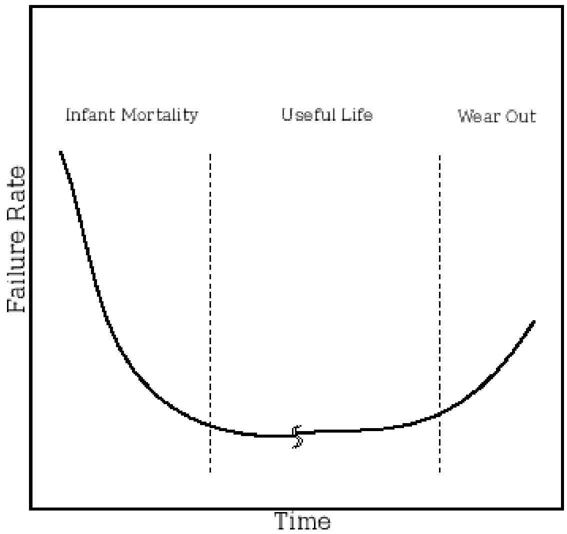


Fig. 3.1: Bathtub hazard function showing a high failure rate during infancy, a low, nearly constant rate during the useful life, and a raising failure rate due wear out at the end of the lifetime.

In this theory, the lifetime of a system is split into three major parts. In the first part a high failure rate can be observed, called the infant mortality. This is reasoned to be due to major weaknesses in materials, production defects, faulty design, omitted inspections, and mishandling. These failures are also considered as extrinsic failures and it is suggested that all systems with gross defects fail during the early operation time. This leads to the next period, the system's useful time. Here, a low failure rate can be observed. This part is often modeled using a constant failure rate. Therefore, the probability of a system to fail is randomly distributed. Even though this assumption is heavily debated, many reliability calculations are based on such a constant rate. At the end of the lifetime, the wear out period follows due to fatigue of materials. An intelligent product design makes sure that wear out occurs after some time greater than the planned lifetime of the product.

The concepts of Electronic Equipment and Reliability

Electronic Equipment is defined as equipment which is dependent on electric currents or electromagnetic fields in order to work properly. Electronic components have a wide range of failure modes. These can be classified in various ways, such as by time or cause. Failures can be caused by excess temperature, excess current or voltage, ionizing radiation, mechanical shock, stress or impact, and many other causes. In semiconductor devices, problems in the device package may cause failures due to contamination, mechanical stress of the device, or open or short circuits.

The telecommunications industry has devoted much time over the years to concentrate on developing reliability models for electronic equipment. One such tool is the automated reliability prediction procedure (ARPP), which is an Excel-spreadsheet software tool that automates the reliability prediction procedures in SR-332, Reliability prediction procedure for electronic equipment. FD-ARPP-01 provides suppliers and manufacturers with a tool for making reliability prediction procedure (RPP) calculations. It also provides a means for understanding RPP calculations through the capability of interactive examples provided by the user.

The RPP views electronic systems as hierarchical assemblies. Systems are constructed from units that, in turn, are constructed from devices. The methods presented predict reliability at these three hierarchical levels:

a. Device: A basic component (or part)

b. Unit: Any assembly of devices. This may include, but is not limited to, circuit packs, modules, plug-in units, racks, power supplies, and ancillary equipment. Unless otherwise dictated by maintenance considerations, a unit will usually be the lowest level of replaceable assemblies/devices. The RPP is aimed primarily at reliability prediction of units.

Importance of Reliability Predictions

Reliability predictions have much relevance in electronic equipment and products, these include;

- Reliability predictions help assess the effect of product reliability on the maintenance activity and on the quantity of spare units required for acceptable field performance of any particular system. For example, predictions of the frequency of unit level maintenance actions can be obtained. Reliability prediction can be used to size spare populations.
- They provide necessary input to system-level reliability models. System-level reliability models can subsequently be used to predict, for example, frequency of system outages in steady-state, frequency of system outages during early life, expected downtime per year, and system availability.
- They provide necessary input to unit and system-level life cycle cost analyses. Life cycle cost studies determine the cost of a product over its entire life. Therefore, how often a unit will have to be replaced needs to be known. Inputs to this process include unit and system failure rates. This includes how often units and systems fail during the first year of operation as well as in later years.
- They assist in deciding which product to purchase from a list of competing products. As a result, it is essential that reliability predictions be based on a common procedure.
- They can be used to set factory test standards for products requiring a reliability test. Reliability predictions help determine how often the system

should fail.
- They are needed as input to the analysis of complex systems such as switching systems and digital cross-connect systems. It is necessary to know how often different parts of the system are going to fail even for redundant components.
- They can be used in design trade-off studies; For example, a supplier could look at a design with many simple devices and compare it to a design with fewer devices that are newer but more complex. The unit with fewer devices is usually more reliable.
- They can be used to set achievable in-service performance standards against which to judge actual performance and stimulate action.

The concepts of Redundancy in System Reliability

Redundancy is process where in a system designs components are duplicated to provide alternative in case of failure. Redundancy is a common approach to improve the reliability and availability of a system. Adding redundancy may increase the cost and complexity of a system but will increase reliability. Designs with the high reliability of modern electrical and mechanical components applications may not need redundancy in order to be successful. However, if the cost of failure is high enough, redundancy may be an attractive option.

Probability Equation to Calculate Reliability

Reliability is a statistical probability and there are no absolutes or guarantees. The goal is to increase the odds of success as much as you can within reason.
The following equation is the probability equation most commonly used in industry to calculate reliability. This equation assumes that you have a constant failure rate (λ).

$$R(t) = e^{-\lambda t}$$

Where: R (t) is the probability of success
t is the mission time, or the time the system must execute without an outage
λ is the constant failure rate over time (N failures/hour)
1/λ is the Mean Time To Failure (MTTF)
Usually, the only factor that can have an impact on this is the failure rate (λ). The environment is determined by the nature of the application itself. You cannot normally change the mission time, unless you can work in planned maintenance at strategic times. Therefore, you can best influence the reliability of your system through prudent part selection and design practices.
Another way to calculate reliability is to take the probability equation and instead solve for the mean time to failure (MTTF) of the system:

$$R(t) = e^{-\lambda t} = e^{-t/MTTF}$$

Solving for MTTF:

$$MTTF = - (t / \ln [R(t)])$$

For example, if your application had a mission time of 24 hours a day, 7 days a week, for one year (24/7/365) and you experienced a success rate of 90%:

$$MTTF = - (1 \text{ yr} / \ln [.90]) = 9.49 \text{ years}$$

If you add redundancy, then the success rate increases to approximately 99% for the same mission time:

$$MTTF = - (1 \text{ yr} / \ln [.99]) = 99.50 \text{ years}$$

These equations effectively demonstrate the vast improvement in reliability that redundancy can bring to any system.

Redundancy Improves Reliability

Basic math demonstrates how redundant system design practices can improve your system reliability:
Based on mathematical set theory, all applications are either successful or not successful (a failure). If R is the probability of success and F is the probability of failure. Thus the sum of the two logical states is unity.
Therefore we can state that:

$$R + F = 1$$

Because most companies tend to track failures more than successes, you can turn the equation around to calculate reliability:

$$R = 1 - F$$

The following example uses a 10% probability of failure:

$$R = 1 - 0.1 = 0.90$$

The probability of success for a given system would be 90%, or 90 out of 100 should succeed.

To use this concept to calculate the reliability of a redundant system, use the following equation:

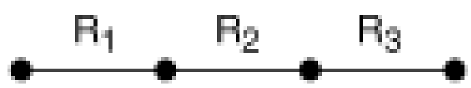
$$R = 1 - (F_1)(F_2)$$

If systems 1 and 2 are redundant systems, meaning that one system can functionally back up the other, then F_1 is the probability of failure of system 1 and F_2 is the probability of failure of system 2.
If we leverage redundancy, the probability of success for a given system would be 99%, or 99 out of 100 should succeed:

$$R = 1 - (0.1)(0.1) = 0.99$$

Levels of Redundancy

There are many situations where it might be more beneficial to employ redundancy only to a less reliable component of the system.
The following model depicts a system that has three dependent components in series. If one component fails, the entire system fails.



R_1 = Component 1 reliability
R_2 = Component 2 reliability
R_3 = Component 3 reliability

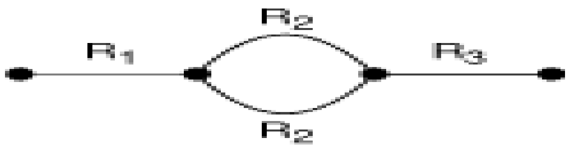
You can calculate the reliability of the entire system by multiplying the reliability of each of the components together.

$R_{system} = (R_1) (R_2) (R_3)$

For an example, if $R_1 = 0.98$, $R_2 = 0.85$, and $R_3 = 0.97$, then the reliability of the system would be:

$R_{system} = (0.98) (0.85) (0.97) = 0.81$

If you back up just the least reliable component of the system, R_2, with redundancy, the model now looks like this:



Remember, since:

$R = 1 – F$

And for a redundant component:

$R = 1 - (F_1) (F_2)$

The reliability equation of the system now looks like this:

$R_{system} = (R_1) (1-(F_2) (F_2)) (R_3)$

If you recalculate the example for $R_1 =.98$, $R_2 =.85$, and $R_3 =.97$, the reliability of the system is now:

$R_{system} = (.98) (1 - (.15) (.15)) (.97) =.93$

We have improved the reliability of the system by 12 percentage points by implementing redundancy for only one component.

There are many levels at which one can implement this strategy and it is application specific. One has to understand which components are most likely to fail. It may be at the sensor, the cabling, the device, the chassis, the power supply, or any number of other components of the system.

Redundancy Improves Availability

Availability is the percentage of time that a system is up and running for a particular mission time.

Availability = Uptime/(Uptime + Downtime)

If you have a mission time of 24/7 for six months and have no downtime, then you would have 100% availability. If you have one day of downtime for that same mission, then the availability of the system becomes 99.4%.

Mission Time	Total Downtime	Availability
24/7 for 1 year	1.2 months	90.0%
24/7 for 1 year	3.7 days	99.0%
24/7 for 1 year	8.8 hours	99.9%
24/7 for 1 year	5.3 minutes	99.999%
24/7 for 1 year	3.2 seconds	99.99999%

When you are developing strategies for improving availability, you must first accept the reality that you will have to deal with failures occasionally. So the focus in designing any system for high availability is to reduce downtime and make the repair time as short as possible.

Without redundancy, the system downtime depends on how quickly you can:

1. Detect the failure.
2. Diagnose the problem.
3. Repair or replace the failed part of the system.
4. Return the system to full operational status.

For hardware failures, the best solution is to replace the bad component or system. Depending on the accessibility and availability of spares, replacement could take anywhere from a few minutes to several days. If you encountered a software failure, you may only need to reboot the system to temporarily repair it. However, rebooting could take from a few seconds to multiple hours, depending on the complexity of the system.

With redundancy, the system downtime is dependent on how fast you can detect a failure and switch over to the backup unit. This is easily under one second and many systems can achieve sub-millisecond downtimes. Redundancy can therefore improve the availability of your system by several orders of magnitude.

For example, consider a system that needs to run 24/7 for one year. If it experiences one hour of downtime during the mission, the availability would be 99.9% (or 3 nines in availability-speak.) If you use redundancy and the downtime is one second, the availability would be 99.99999% or 7 nines.

Another important concept to remember is that the switchover times for redundancy are commonly so fast that the system is not noticeably affected by the downtime. Thus, for all practical purposes, the system never experienced an outage, thus achieving 100% availability.

Factors Affecting Reliability

1. Design factors: some failures are due to design shortcomings in the design and application of the components. Making units of the design rugged through careful design and controlled overstressed testing is a very important part of making the product reliable.
2. Complexity: keep things simple what is not there cannot fail. Every component used will contribute to system unreliability.
3. Stress: the most prominent stress in electronic equipment are temperature, voltage, vibration and temperature rise due to current. Care should be taken on each of this stress upon each units of component when designing.

Importance of reliability

Once the reliability of a system has been determined, engineers are often faced with the task of identifying the least reliable component(s) in the system in order to improve the design. If the reliability of the system is to be improved, then the efforts can best be concentrated on improving the reliability of that component first. In simple systems such as a series system, it is easy to identify the weak components. However, in more complex systems this becomes quite a difficult task. For complex systems, the analyst needs a mathematical approach that will provide the means of identifying and quantifying the importance of each component in the system.

Commercial aircraft are required to have multiple redundant computing systems, hydraulic systems, and

propulsion systems so that a single in-flight equipment failure will not cause loss of life. Also the Internet which relies on a backbone of routers that provides the ability to automatically re-route communication without human intervention when failures occur is a function of reliability.
Satellites placed into orbit around the earth must include massive active redundancy to ensure operation will continue for a decade or longer despite failures induced by normal failure, radiation-induced failure, and thermal shock.
This strategy now dominates space systems, aircraft, and missile systems. Any system or equipment that is not reliable is dangerous to operate.
The main objectives or importance of reliability in electronic equipment is to provide information as a basis for decision making. Some of the applicable areas include:

a) Risk Analysis: Reliability helps to identify potential accidental events in a system and possibly helps to prevent it.
b) Environmental Protection: Reliability studies can be used to improve the designs and operational regulations of antipollution system.
c) Quality Control: Reliability and quality are synonymous to each other; improving reliability ensures quality of products.
d) Optimization of Maintenance and Operation: Reliability ensures optimization of maintenance and operation of products and services.
e) Engineering Designs: Reliability is considered to be one of the most important quality characteristics of technical products.

Conclusions and Recommendations

A design engineer should consider reliability as a cardinal issue. Any equipment that does not have a good percentage of reliability cannot be trusted and therefore will not enjoy good patronage. Even human beings like to relate with people that are reliable. Going by the aforementioned, it is worth trading off cost for reliability by insisting on quality and possibly introducing redundancy where failure may result to great lost or even fatality. They are two major ways of increasing reliability of a system, one is by using reliable components when designing and manufacturing and the second is by introducing redundancy. Reliability have so much advantage, it helps in risk analysis, quality control, identification and prevention of accidents and so on. It is true that to ensure reliability increase cost of equipment which could be a disadvantage but the advantages over the disadvantages determines the quality.

References

1. Kankan, I (2013) *International Journal of Research in computer and communication engineering: system reliability and challenges of electronics* [online]. Available from www.rroij.com [accessed 2nd April 2017].
2. Marvin R., Aruljot H. (2004*) System Reliability Theory:Model Statistical methods and application* [2nd Edition]. (Pp91-96 available from www.sciencepublishinggroup.com [accessed 24th March 2017].
3. Poole, I. (2012) *Reliability Engineering.*[online] available from Wikipedia.com [accessed15th April 2017].
4. Poole, I. (2012) *Reliability Objectives.*[online] available from Wikipedia.com [accessed15th April 2017].
5. Poole, I. (2012)*Principle of Reliability.[*online] available from Wikipedia.com [accessed15th April 2017]
6. Poole, I. (2012) *Reliability and Maintainability of Electrical and Electronics Systems.*[online] available from Wikipedia.com [accessed 15th April 2017].
7. Roberts, P. et al (2006) Reliability and Validity in Research; Nursing Slandered [online]. Available from www.rroij.com [accessed 20th April 2017].
8. Ross, G. et al (2010) *Jet Publication labouratory: Active versus Standby Redundancy for Improved Cryocooler Reliability in space*. [online]. Available from www.rroij.com [accessed 15th April 2017].
9. Vyachester, A., Kharchenko, N. (2012) problems of Reliability of Electronics System..[online] available from Wikipedia.com [accessed 15th April 2017].