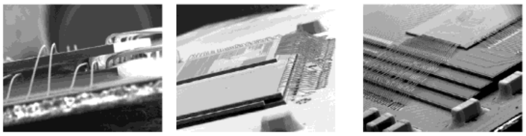
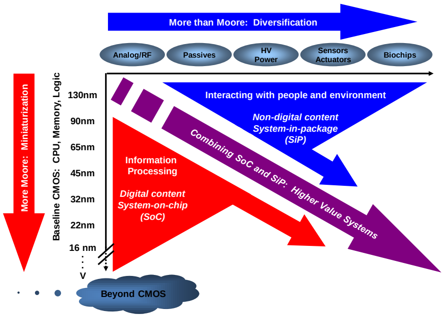
Micro and Nano- Electronics Reliability
Classical approach and new trends

Part 2: Mathematical point of view



Moore's Law & More

ITRS public conference
San Francisco July 13,
2010



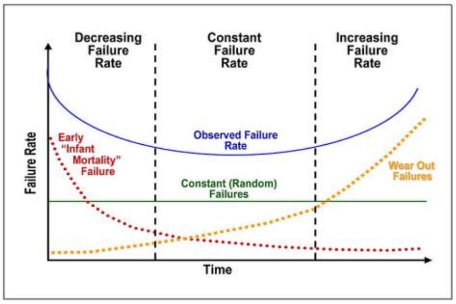
More than Moore: Diversification
Analog/RF
Passives
HV Power
Sensors Actuators
Biochips
More Moore: Miniaturization
Baseline CMOS: CPU, Memory, Logic
130nm
90nm
65nm
45nm
32nm
22nm
16 nm
V
Interacting with people and environment
Non-digital content System-in-package (SiP)
Information Processing
Digital content System-on-chip (SoC)
Combining SoC and SiP: Higher Value Systems
Beyond CMOS

Challenges

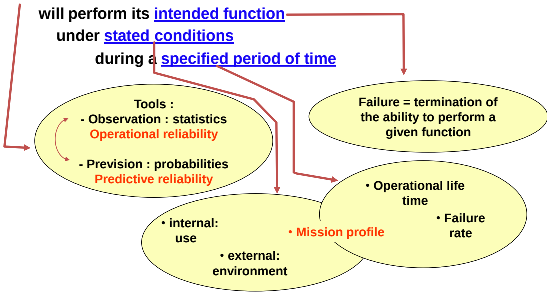
- Multi-scale in both geometric and time domains
- Multi-technology, multi-loading and multi-discipline
- Multi-material and multi-interface
- Multi-failure mechanism, multi-failure mode and multifailure location
- Strongly non-linearity
- Stochastic in nature
- Strongly time and temperature dependent

Probabilistic reliability

Bathtub curve



« Probabilistic » definition of reliability



Probability that a device
will perform its intended function
under stated conditions
during a specified period of time

Tools :
- Observation : statistics
Operational reliability
- Prevision : probabilities
Predictive reliability

Failure = termination of the ability to perform a given function

• Operational life time
• Failure rate
• Mission profile
• internal: use
• external: environment

Mathematical tools

« Probabilistic » definition of reliability: consequences

1 - Reliability is a probability

- Failure is regarded as a random phenomenon
  - recurring event
  - no information on
    - individual failures
    - causes of failures
    - relationships between failures
  - The likelihood for failures to occur varies over time according to a given probability function

- Reliability engineering is concerned with meeting
  - the specified probability of success
  - at a specified statistical confidence level

Statistical study on a large sample size

- Hypotheses
  Non-repairable systems
  Dates of operation normalized at t = 0

large sample size = large number of samples

→ Use of continuous functions

Reliability mathematics definitions

N: Total number of samples
D(t): Number of samples failed at time t
S(t): Number of survivors at time t
t_n: Instants of Failure
F(t): failure function F(t)=D(t)/N
R(t) : reliability function R(t)= S(t)/N

D(t)+S(t) = N

F(t) +R(t) = 1
(no unit)

f (t) = density of defects
= proportion of failures per unit time

$$f(t) = \frac{dF(t)}{dt} = -\frac{dR(t)}{dt}$$

λ (t): Failure Rate = Proportion of failures per unit time, compared to survivors

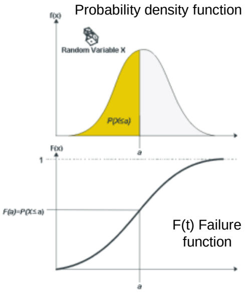
$$\lambda(t) = \frac{1}{R(t)} f(t) = -\frac{1}{R(t)} \frac{dR(t)}{dt}$$

$$\lambda(t) = \frac{1}{S(t)} \frac{dD(t)}{dt}$$

Unit: s^{-1}

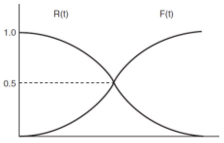
Reliability mathematics definitions

Probability density function f



F(t) Failure function

Relationship of the reliability and failure functions



Mean time BEFORE failure : mean time TO failure
MTBF or MTTF

- MTTF Mean Time TO Failure is an estimate of the average, or mean time until a component's first failure. It is also called “Mean Time Before Failure”
- “Mean time until a failure” assumes that the product CAN NOT be repaired and the product CAN NOT resume any of it’s normal operations.
- It must not be confused with Mean Time Between Failure applicable for repairable systems.

- Mean Time Before Failure describes the average time to failure of a product, even when failure rate is increasing over time (wear-out mode).
- Some units will fail before the mean life, *and some will last longer.*

Reliability mathematics definitions

- R(t) Reliability function:
  - Gives the probability of an item operating for a certain amount of time without failure.
  - Is a function of time, in that every reliability value has an associated time value. In other words, one must specify a time value with the desired reliability value, for instance 95% reliability at 100 hours.
- F(t) Failure function
  - Gives the probability that an item will fail by time t
  - F(t) =Prob(failure will occur before t) = Prob(TTF≤ t)

$$F(t) = \int_0^t f(u)du$$

Where f(t) is the probability density function of the time to failure random variable TTF

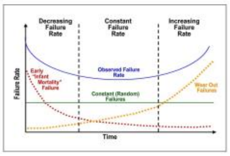
Some words about the failure rate

- Failure rate λ is the indicator of the impact of ageing on the reliability of the system.
- It quantifies the risk of failure, as the age of the system increases

$$\lambda(t) = \frac{1}{S(t)}\frac{dD(t)}{dt} = \frac{N}{S(t)}\frac{dF(t)}{dt} = -\frac{1}{R(t)}\frac{dR(t)}{dt} \quad \text{with } R(0) = 1$$

$$\Rightarrow \quad \boxed{R(t) = e^{-\int_0^t \lambda(u)du}}$$

$$MTBF = \int_0^\infty tf(t)dt = -\int_0^\infty t\frac{dR}{dt}dt$$



MTTF: practical example

- For example, assume you tested 3 identical systems starting from time 0 until all of them failed. The first system failed at 10 hours, the second failed at 12 hours and the third failed at 13 hours. The MTTF is the average of the three failure times, which is 11.6667 hours.
- If these three failures are random samples from a population and the failure times of this population follow a distribution with a probability density function f(t) , then the population MTTF can be mathematically calculated by:

$$MTTF = \int_0^\infty tf(t)dt = -\int_0^\infty t\frac{dR}{dt}dt$$

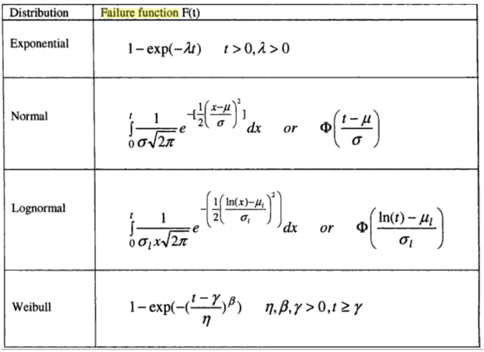
Some words about the failure rate

- Failure rate λ is expressed in s^{-1}

FIT Definition

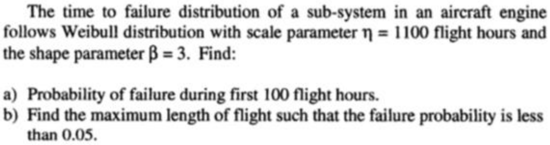
- Because the failure rates are very low, definition of a new unit : FIT
- FIT = Failure in time
- 1 FIT = one failure per billion (10^9) hours
- For example 1 FIT means 1 failure in 10^7 units after 100 hours of operation
- Or 1 failure in 10^6 units after 1000 hours
- And so on

Common used failure functions



Distribution	Failure function F(t)
Exponential	$1-\exp(-\lambda t) \quad t>0, \lambda>0$
Normal	$\int_0^t \frac{1}{\sigma\sqrt{2\pi}} e^{-[\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2]} dx \quad or \quad \Phi\left(\frac{t-\mu}{\sigma}\right)$
Lognormal	$\int_0^t \frac{1}{\sigma_l x\sqrt{2\pi}} e^{-\left(\frac{1}{2}\left(\frac{\ln(x)-\mu_l}{\sigma_l}\right)^2\right)} dx \quad or \quad \Phi\left(\frac{\ln(t)-\mu_l}{\sigma_l}\right)$
Weibull	$1-\exp(-(\frac{t-\gamma}{\eta})^\beta) \quad \eta, \beta, \gamma > 0, t \geq \gamma$

Exercices

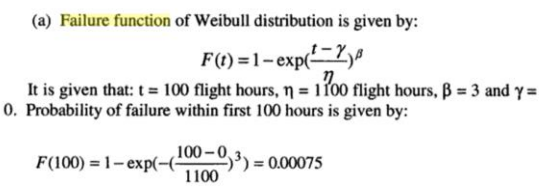


The time to failure distribution of a sub-system in an aircraft engine follows Weibull distribution with scale parameter η = 1100 flight hours and the shape parameter β = 3. Find:

a) Probability of failure during first 100 flight hours.
b) Find the maximum length of flight such that the failure probability is less than 0.05.

NB: Time starts at 0 , that is γ is taken equal to 0

Solution (1/2)



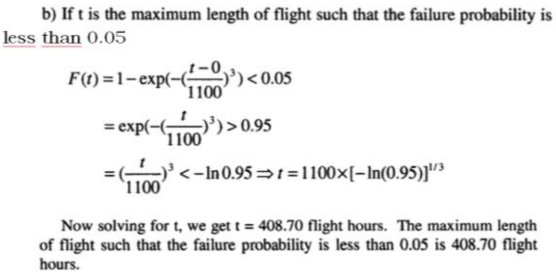
(a) Failure function of Weibull distribution is given by:

$$F(t) = 1 - \exp(\frac{t-\gamma}{\eta})^{\beta}$$

It is given that: t = 100 flight hours, η = 1100 flight hours, β = 3 and γ = 0. Probability of failure within first 100 hours is given by:

$$F(100) = 1 - \exp(-(\frac{100-0}{1100})^{3}) = 0.00075$$

Solution (2/2)



b) If t is the maximum length of flight such that the failure probability is less than 0.05

$$F(t) = 1 - \exp(-(\frac{t-0}{1100})^{3}) < 0.05$$

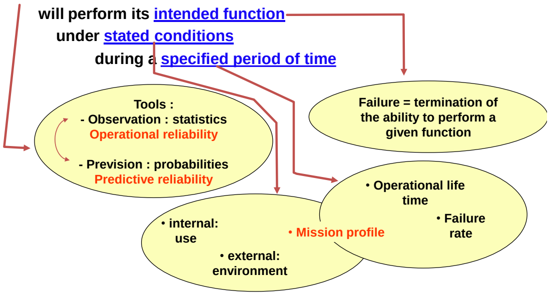
$$= \exp(-(\frac{t}{1100})^{3}) > 0.95$$

$$= (\frac{t}{1100})^{3} < -\ln 0.95 \Rightarrow t = 1100 \times [-\ln(0.95)]^{1/3}$$

Now solving for t, we get t = 408.70 flight hours. The maximum length of flight such that the failure probability is less than 0.05 is 408.70 flight hours.

Mission profile

« Probabilistic » definition of reliability



Probability that a device
will perform its **intended function**
under **stated conditions**
during a **specified period of time**

Tools :
- Observation : statistics
Operational reliability
- Prevision : probabilities
Predictive reliability

Failure = termination of the ability to perform a given function

• Operational life time
• Failure rate

• internal: use
• external: environment
• Mission profile

« Probabilistic » definition of reliability: consequences

2 - Reliability is predicated on "intended function"

- Generally, this is taken to mean “operation without failure”.
- However, even if no individual part of the system fails, but the system as a whole does not do what was intended, then it is still charged against the system reliability

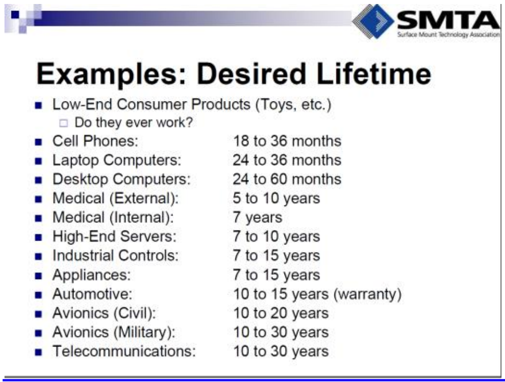
• The system requirements specification is the criterion against which reliability is measured.

Out of spec use

« Probabilistic » definition of reliability: consequences

3 - Reliability applies to a specified period of time

In practical terms, this means that a system has a specified chance that it will operate without failure before a given time



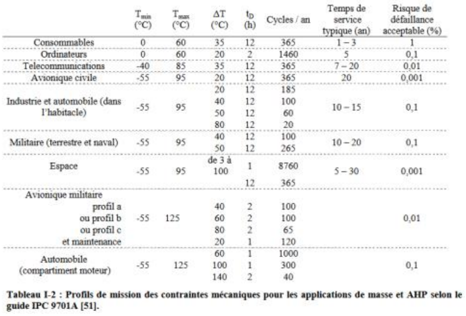
SMTA
Surface Mount Technology Association

Examples: Desired Lifetime

Low-End Consumer Products (Toys, etc.) ☐ Do they ever work?	
Cell Phones:	18 to 36 months
Laptop Computers:	24 to 36 months
Desktop Computers:	24 to 60 months
Medical (External):	5 to 10 years
Medical (Internal):	7 years
High-End Servers:	7 to 10 years
Industrial Controls:	7 to 15 years
Appliances:	7 to 15 years
Automotive:	10 to 15 years (warranty)
Avionics (Civil):	10 to 20 years
Avionics (Military):	10 to 30 years
Telecommunications:	10 to 30 years

Expected lifetime for transportation systems : traction conditions

Urban Railway -40°C +45°C	**Urban Bus** -40°C +45°C	**Urban Auto** -40°C +45°C	**Aircraft** *-60°C + 50°C*
Cycles **5 millions** **Inter-station stops**	**1 million** **Traffic stop-start**	**> 800 000** **Traffic stop-start**	***25 000 ?*** ***flight***
Expected Lifetime **100 000 h** **30-40 years**	**30 000 h** **12 years**	**5 to 7 000 h** **12 years**	***50 000 h ?*** ***30 years ?***



	T_{min} (°C)	T_{max} (°C)	ΔT (°C)	t_D (h)	Cycles / an	Temps de service typique (an)	Risque de défaillance acceptable (%)
Consommables	0	60	35	12	365	1 – 3	1
Ordinateurs	0	60	20	2	1460	5	0,1
Telecommunications	-40	85	35	12	365	7 – 20	0,01
Avionique civile	-55	95	20	12	365	20	0,001
Industrie et automobile (dans l'habitacle)	-55	95	20 40 50 80	12 12 12 12	185 100 60 20	10 – 15	0,1
Militaire (terrestre et naval)	-55	95	40 50	12 12	100 265	10 – 20	0,1
Espace	-55	95	de 3 à 100	1 12	8760 365	5 – 30	0,001
Avionique militaire profil a ou profil b ou profil c et maintenance	-55	125	40 60 80 20	2 2 2 1	100 100 65 120		0,01
Automobile (compartiment moteur)	-55	125	60 100 140	1 1 2	1000 300 40		0,1

Tableau I-2 : Profils de mission des contraintes mécaniques pour les applications de masse et AHP selon le guide IPC 9701A [51].

« Probabilistic » definition of reliability: consequences

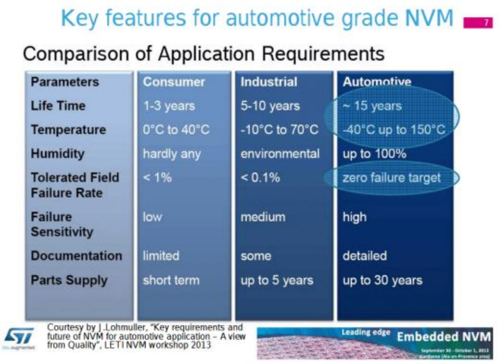
4 - Reliability is restricted to operation under stated conditions

- Impossible to design a system for unlimited conditions
  - ➢ The operating environment must be addressed during design and testing

Solar panels on Mars Rover

Solar panels on sailing boat

Mission profile: a key factor



Key features for automotive grade NVM

Comparison of Application Requirements

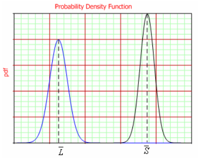
Parameters	Consumer	Industrial	Automotive
Life Time	1-3 years	5-10 years	~ 15 years
Temperature	0°C to 40°C	-10°C to 70°C	-40°C up to 150°C
Humidity	hardly any	environmental	up to 100%
Tolerated Field Failure Rate	< 1%	< 0.1%	zero failure target
Failure Sensitivity	low	medium	high
Documentation	limited	some	detailed
Parts Supply	short term	up to 5 years	up to 30 years

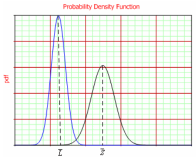
Courtesy by J.Lohmuller, "Key requirements and future of NVM for automotive application – A view from Quality", LETI NVM workshop 2013

The strength-load approach

The strength-load approach

- Process dispersion is one factor which controls reliability in electronic devices.
- Load distribution, issued from the spreading of stresses applied to the component in its mission profile has also a major influence.
- The crossing between the highest stresses values of the mission profile and the low side of strength distribution tail results in the occurrence of failure.

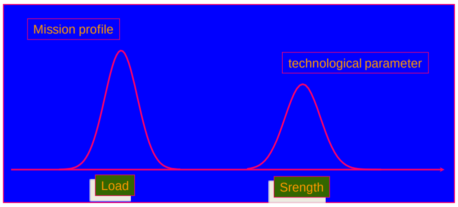




The strength-load approach

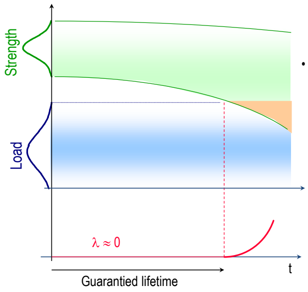
- For every critical technological parameter, the strength-load relationships is of course determined through degradation law where stressing factor influences, such as
  - temperature,
  - humidity,
  - voltage ones
  - etc.,

are related to the device attributes, all of them being represented by a distribution function.

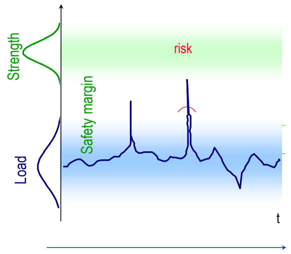


* Analysis of the mission profile
* Determination of maximum stress during use
* Analysis of possible overloads

* Robustness of the component
* Dispersion of critical parameters
* Process control
* Elimination of tails of weak parts
* *Identification of weak parameters*
⇨ *technological choice*



- Wear out : weakening of the systems

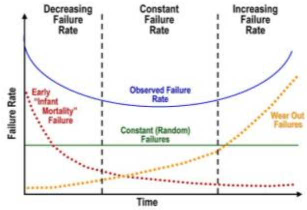


Loads are variable

Loads must be estimated

The bathtub curve

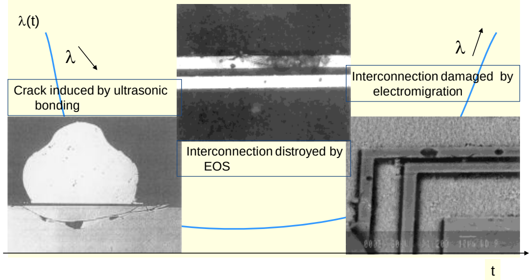
The Bathtub curve and product failure behavior



λ(t) : Failure Rate
Proportion of failures
per unit time,
compared to survivors

- The bathtub curve consists of three periods
  - ➢ an infant mortality period with a decreasing failure rate
  - ➢ a normal life period (also known as "useful life") with a low, relatively constant failure rate
  - ➢ a wear-out period that exhibits an increasing failure rate

Failure types



Crack induced by ultrasonic bonding

Interconnection distroyed by EOS

Interconnection damaged by electromigration

Life cycle of a component

Life stages

Design
Manufacturing and rework
Test
Screening""
Storage
Handling
Transportation
Operational life
Repair

Stresses

- T
- ΔT
- Vibrations
- Moisture
- Radiations
- I, V
- EMC
- Chemical
- Dusts
- Pressure

The bathtub curve
PART 1
Infant mortality

Infant mortality

- Failures during infant mortality are *highly undesirable and are always caused by defects and blunders:*
  - ➢ material defects,
  - ➢ design blunders
  - ➢ errors in assembly, etc.

- Infant mortality does not mean "*products that fail within 90 days*" or any other defined time period.

- Infant mortality is the time over which the failure rate of a product is decreasing, and may last for years.

Infant mortality

- These latent defects are process/ manufacturing defects
  - ➢ Substrate quality
  - ➢ Photoetching cleanness
  - ➢ Thin oxide defects (MOS)
  - ➢ Assembly defects (welding / brazing)

- They can be reduced by
  - ➢ Process control
  - ➢ Improved technology
  - ➢ Quality Manufacturing
  - ➢ Process Control
  - ➢ *Burn in*

Infant mortality : Elimination of design and material defects

- In addition to the best design approaches, stress testing should be started at the earliest development phases
  - ➢ to evaluate design weaknesses
  - ➢ to uncover specific assembly and materials problems.
    - ✓HALT (Highly Accelerated Life Test)
    - ✓HAST (Highly Accelerated Stress Test)
    - ✓with increasing stress levels as needed
- The failures should be investigated and design improvements should be made to improve product robustness.

Infant mortality : Elimination of design and material defects

- After manufacturing of a product begins, a stress test can still be valuable. There are two distinct uses for stress testing in production.
  - ➢ HASA, (Highly Accelerated Stress Audit) to identify defects caused by assembly or material variations that can lead to failure and to take action to remove the root causes of these defects.
  - ➢ burn-in: use of stress tests as an ongoing 100% screen to weed out defects in a product where the root causes cannot be eliminated.
- The first approach, eliminating root causes, is generally the best approach and can significantly reduce infant mortalities.
- Burn in is usually most cost-effective only for early production as root causes are identified, the process/design is corrected and significant problems are removed.

The bathtub curve
PART 2
Useful or normal life

Normal life

- Residues of early failures / first wear-out failures
- “Random” defects
  - ➢ Erratic overloads (power line surges for instance)
  - ➢ Cosmic radiation (alpha particles and cosmic rays)
  - ➢ Misuse
  - ➢ Overstresses

Overstresses

- Electrical overstress mechanisms: EOS and ESD
  - ➢ Basically, ESD is defined as a short duration phenomena (less than 1 µs) and EOS covers everything else of a longer duration: from a part plugged in backwards, to noise spikes on a power supply, to severe mismatch of output terminations.
- Thermal overstress mechanisms
  - ➢ nominally manifested in damage to packaging or assembly components
- Mechanical overstress mechanisms

Useful life : mathematical aspects
EXERCISE

- Exercise : During the useful life, the failure rate is approximately constant : $\lambda(t) = \lambda_0$
- Determine :
  - ➢ The failure function $F(t)=D(t)/N$
  - ➢ The reliability function $R(t)= S(t)/N$
  - ➢ The failure density function $f(t)$
  - ➢ The relationship between MTTF and λ_0

Reminder: Reliability mathematics definitions

N: Total number of samples
D(t): Number of samples failed at time t
S(t): Number of survivors at time t
t_n: Instants of Failure
F(t): failure function F(t)=D(t)/N
R(t) : reliability function R(t)= S(t)/N

D(t)+S(t) = N

F(t) +R(t) = 1

f (t) = density of defects
= proportion of failures per unit time

$$f(t) = \frac{dF(t)}{dt} = -\frac{dR(t)}{dt}$$

$$\boxed{R(t) = e^{-\int_0^t \lambda(u)du}}$$

$$MTTF = \int_0^\infty t f(t) dt = -\int_0^\infty t \frac{dR}{dt} dt$$

λ (t): Failure Rate = Proportion of failures per unit time, compared to survivors

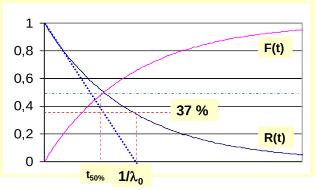
$$\lambda(t) = \frac{1}{R(t)} f(t) = -\frac{1}{R(t)} \frac{dR(t)}{dt}$$

$$\lambda(t) = \frac{1}{S(t)} \frac{dD(t)}{dt}$$

Useful life: mathematical aspects

- For constant failure rate systems, $\lambda(t) = \lambda_0$ MTTF is the inverse of the failure rate.

$\boxed{\lambda(t) = \lambda_0}$ $\boxed{R(t) = e^{-\lambda_0 t}}$ $\boxed{F(t) = 1 - e^{-\lambda_0 t}}$ $\boxed{f(t) = -\frac{1}{\lambda_0} e^{-\lambda_0 t}}$



$$\boxed{MTTF = \frac{1}{\lambda_0}}$$

$$\boxed{t_{50\%} = \frac{\ln 2}{\lambda_0}}$$

Useful life: Numerical example (exercise)

1. What is the failure rate of a product with an MTTF of 3.5 million hours, used 24 hours per day ?
2. Note that 3.5 million hours is 400 years. Do we expect that any of these products will actually operate for 400 years?

Solution

1. MTTF = 1 / failure rate
   - ➢ failure rate = 1 / MTTF = 1 / 3,500,000 hours
   - ➢ failure rate = 0.000000286 failures / hour
   - ➢ failure rate = 0.000286 failures / 1000 hours
   - ➢ failure rate = 0.0286% / 1000 hours - and since there are 8,760 hours in a year

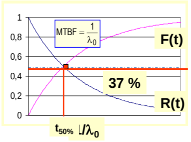
   ❖ Failure rate = 0.25% / year
2. *Any of these products will actually operate for 400 years ?*

   No! Long before 400 years of use, a wear-out mode will become dominant and the population of products will leave the normal life period of the bathtub and start up the wear-out curve.

   But during the normal life period, the "constant" failure rate will be 0.25% per year, which can also be expressed as an MTTF of 3.5 million hours.

100 FIT

If Failure Rate const (exponential distribution) ➡ **MTTF 10000 years**



The bathtub curve
PART 3
Wear-out

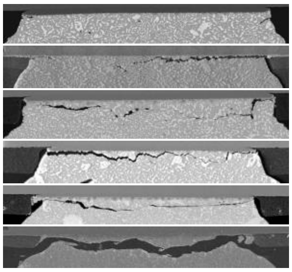
Wear-out phase

- Intrinsic wear-out mechanisms begin to dominate
- Failure rate begins increasing
- Product lifetime is typically defined as the time from initial production until the onset of wear-out.

Wear-out failure mechanisms

- Electromigration
- Stress migration
- Stress-induced voiding (SIV)
- Time dependent dielectric breakdown (TDDB)
- Negative/Positive bias temperature instability (NBTI or PBTI)
- Solder fatigue
- Corrosion
- ….

Wear-out failures

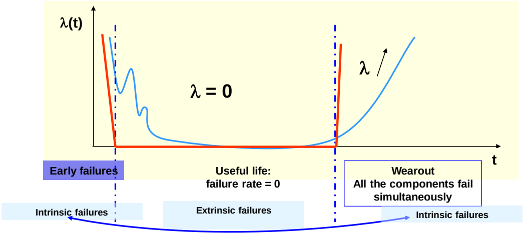


Improved Physical Understanding of Intermittent Failure in Continuous Monitoring Method

W. Maia, M. Brizoux, H. Frémont, Y. Danto Microelectronics and Reliability ,2006,

Ideal life evolution of the component

No failure during useful life
All failure simultaneous



Common used distributions

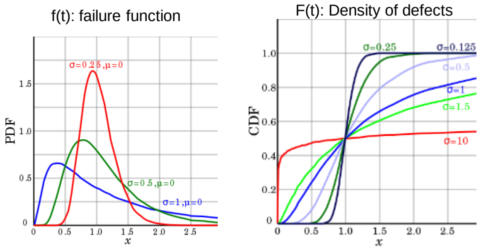
Distribution	Failure function F(t)
Exponential	$1-\exp(-\lambda t) \quad t>0, \lambda>0$
Normal	$\int_0^t \frac{1}{\sigma\sqrt{2\pi}} e^{-[\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2]} dx \quad or \quad \Phi\left(\frac{t-\mu}{\sigma}\right)$
Lognormal	$\int_0^t \frac{1}{\sigma_l x\sqrt{2\pi}} e^{-\left(\frac{1}{2}\left(\frac{\ln(x)-\mu_l}{\sigma_l}\right)^2\right)} dx \quad or \quad \Phi\left(\frac{\ln(t)-\mu_l}{\sigma_l}\right)$
Weibull	$1-\exp(-(\frac{t-\gamma}{\eta})^{\beta}) \quad \eta,\beta,\gamma>0, t\geq\gamma$

Common used distributions: log-normal (or gaussian)

$$f(t)=\frac{1}{\sigma t\sqrt{2\pi}}e^{\left(-\frac{(\ln(t)-\ln(T_{50}))^2}{2\sigma^2}\right)} \qquad F(t)=\int_o^T \frac{1}{\sigma t\sqrt{2\pi}}\mathrm{e}^{\left(-\frac{(\ln(t)-\ln(T_{50}))^2}{2\sigma^2}\right)}\mathrm{d}t$$

- The lognormal life distribution is one wherein the natural logarithms of the lifetime data, ln(t), form a normal distribution.
- The shape parameter sigma σ is the standard deviation
- $T_{50} = t_{50\%}$ is the median time to failure (time at which 50% of the samples fail)

Examples of log-normal curves

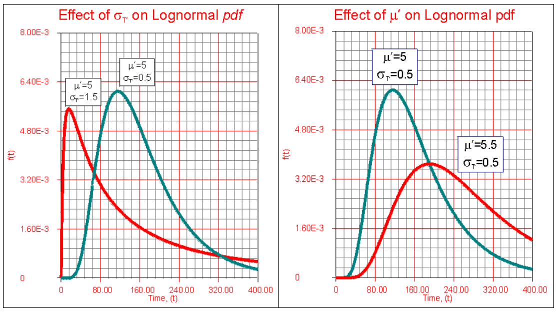

f(t): failure function

F(t): Density of defects

μ: mean of the natural logarithms of the times-to-failure

https://en.wikipedia.org/wiki/Log-normal_distribution

Examples of log-normal curves

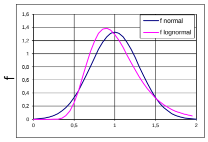


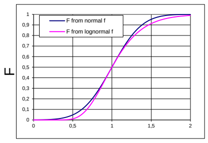
http://www.weibull.com/hotwire/issue47/relbasics47.htm

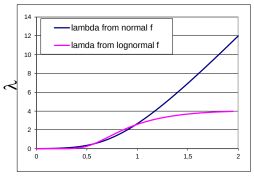
Log-normal distribution

- The life data of a lognormal distribution is a straight line if plotted on a lognormal plot, i.e., a plot whose x- and y-axes stand for the cumulative % of failures and the logarithmic scale of time, respectively.
- σ is the slope of the time to failure vs. the cumulative percent failure on a log scale
- The failure rate curve λ(t) of a lognormal life distribution starts at zero, rises to a peak, then asymptotically approaches zero again for all values of σ.
- The lognormal distribution is formed by the multiplicative effects of random variables. Multiplicative interactions of variables are found in many natural processes, and are in fact observed in many frequently-encountered semiconductor failure mechanisms. This characteristic of the lognormal distribution makes it a good choice for the analysis of the failure rates of many semiconductor failure mechanisms.

Common used distributions: normal and log-normal







λ increases : useful for wear-out

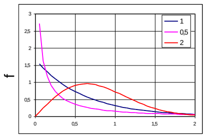
Common used distributions: Weibull

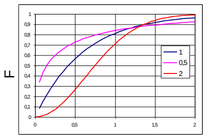
$$f(t) = \frac{\beta}{t}\left(\frac{t}{\alpha}\right)^{\beta} .\exp\left[-\left(\frac{t}{\alpha}\right)^{\beta}\right] \qquad \lambda(t) = \frac{\beta}{\alpha}\left(\frac{t}{\alpha}\right)^{\beta-1}$$

$$F(t) = 1 - \exp\left[-\left(\frac{t}{\alpha}\right)^{\beta}\right] \qquad R(t) = \exp\left[-\left(\frac{t}{\alpha}\right)^{\beta}\right]$$

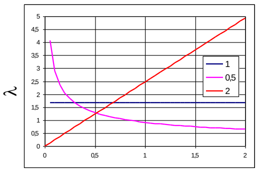
•Depending of β, it can describe
- the infant mortality (β <1) as λ decreases
- the useful life (β =1) as λ is constant
- the wearout (β >1) as λ increases

Weibull distribution





- Weibull distribution
  - Easy to use thanks β parameter
  - Allen-Plait diagram



Allen-Plait diagram

$$F(t) = 1 - e^{-\left(\frac{t}{\eta}\right)^{\beta}} \Leftrightarrow \ln(1 - F(t)) = -\left(\frac{t}{\eta}\right)^{\beta}$$

$$\Leftrightarrow -\ln(1 - F(t)) = \left(\frac{t}{\eta}\right)^{\beta}$$

$$\Leftrightarrow \ln(-\ln(1 - F(t))) = \beta \ln \frac{t}{\eta}$$

$$\Leftrightarrow \ln(-\ln(1 - F(t))) = \beta \ln t - \beta \ln \eta$$

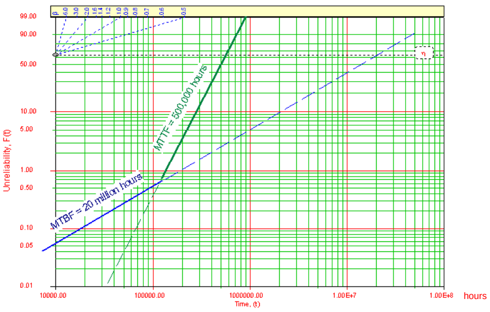
$$\Leftrightarrow Y = \beta X - \beta \ln \eta$$

Exemple de détermination :

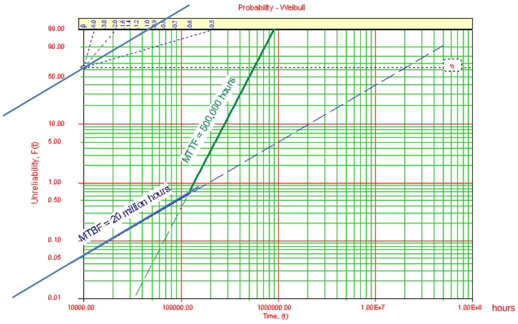
On construit tout d'abord le nuage de points (t ; F(t)) puis une droite d'ajustement D, on lit la valeur du paramètre η sur l'axe des abscisses puis on trace la parallèle D' à la droite D passant par l'origine O du repère, on lit le paramètre β sur l'axe d'équation X = -1.

y scale : ln (- ln (1 - F(t)))
x scale ln(t)

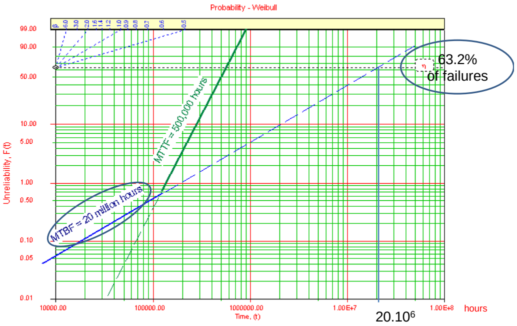
Weibull Plot for Normal Life and Wear-Out Populations
An example



Weibull Plot for Normal Life and Wear-Out Populations
Blue part : β = 1



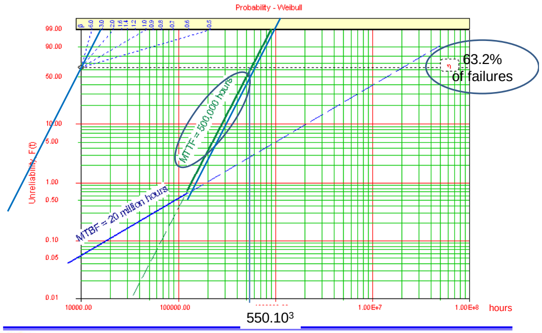
Weibull Plot for Normal Life and Wear-Out Populations
Blue part : β = 1



63.2%
of failures

20.10^6

Weibull Plot for Normal Life and Wear-Out Populations
Green part : β = 3



63.2%
of failures

550.10^3

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