

design **1**st

Design for Reliability

Concepts, Causes and Identification

Design for Reliability

What is Product Reliability?

Reliability is the probability that a product will continue to work normally over a specified interval of time, under specified conditions. For example, the mouse on your computer might have a reliability of 0.990 (or 99%) over the next 1000 hours. It has a 99% chance of working normally during this time, which is obviously the same as saying it has a 1% chance of being faulty.

A more reliable product spends less of its time being maintained, so there is often a design trade-off between reliability and maintainability. Reliability is extremely design-sensitive. Very slight changes to the design of a component can cause profound changes in reliability, which is why it is important to specify product reliability and maintainability targets before any design work is undertaken. This in turn requires early knowledge of the anticipated service life of the product, and the degree to which parts of the product are to be made replaceable.

For example, a ballpoint pen could be:

1. Disposable.

It will be reliable until the ink is exhausted, at which point it is discarded. Neither the ink nor parts of the pen body are replaceable, so the pen body needs to last no longer than the ink. The product has a short service life.

2. Refillable.

It will be designed for routine replacement of ink (usually as an ink cartridge), but pen body parts will not be replaceable. The body must be reliable enough to outlast the specified number of ink replacement cycles. The product has a moderate service life.

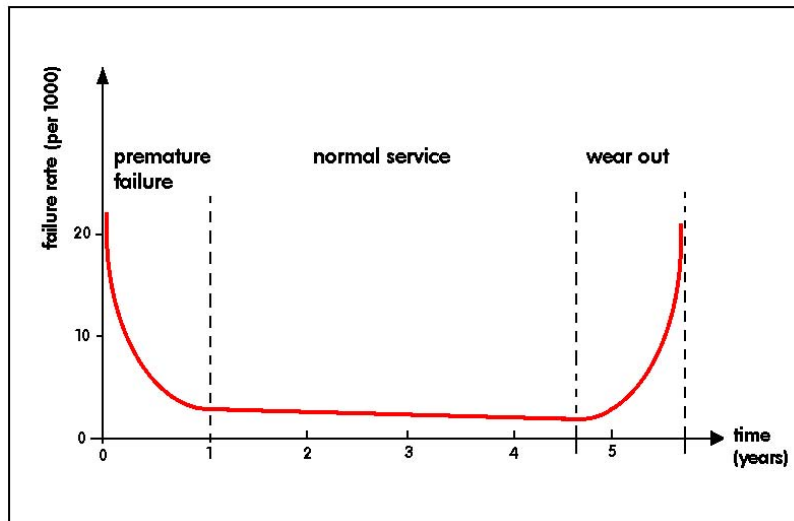
3. Repairable (fully maintainable).

The pen is refillable and all body parts are replaceable. The product has an extendable service life (until the spare parts are no longer available).

Note that product service life is not the same as market life. The market life (also known as the design life) of a product is the length of time the product will continue to be sold in the shops and supported before being withdrawn. For example, a particular brand of disposable razor may have a service life of '3 shaves', but a market life of 10 years.

Reliability & The Bathtub Curve:

For a sufficiently large population of a particular item (component or product), failures will be distributed in time as shown in the graph below. Different times and failure rates will obviously apply to different kinds of item, although the general shape of the curve will be similar in all cases. The graph goes by the name of ‘the bathtub curve’ because of its characteristic shape. Note that the highest failure rates correspond to premature failure (sometimes called ‘infant mortality’), and to end-of life wear out.



While we expect our products to fail after some years of useful service, premature failures are particularly undesirable and are almost always the result of bad design or sloppy manufacturing. Premature failures can be largely eliminated by identifying and designing out the component failure modes, illustrated in the table below:

Life phase	Cause of failure	Prevention / remedy
Premature failures	Component is good but inappropriately installed.	Installation method is part of design responsibility.
Premature failures	Component is damaged during product assembly.	Liaison with production management – change component design or assembly method.
Premature failures	Component is damaged during product maintenance.	Adjust design according to field data. Adopt ‘design for maintainability’.
Premature failures	Overall product design is poor and introduces unnecessarily high stress levels throughout.	Back to the drawing board.
Normal service phase (random) failures	Careless handling. Accidents.	Ruggedize, examine product with respect to shock and vibration.
	Severe natural phenomena (lightning, freak weather, sun-storms, meteorites). Acts of War.	Ruggedization, otherwise no economic remedy.
Wear-out failures	Mechanical wear. Component wears out at the end of its declared life (through abrasion or material depletion). E.g. tires	Consider product maintenance or disposal. E.g. replace tires
	Component wears out before reaching its intended life.	Increase specification, ruggedize, reduce stress environment, revise target life

Causes of component failure

A product is usually a system of inter-connected components, although very simple products might consist of only one component – a metal teaspoon for example. In either case, component failure usually leads to failure of the whole product. There are many reasons why a component in a product might fail, but these can be gathered into broad groups as follows:

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	Random failures in VLSI (electronic) components due to background radiation.	Design product software to validate device output data.
	Natural ageing -component material degrades by exposure to air and light (e.g. the rubber pinch rollers in a tape recorder will go soft and 'perish' over time).	Change material specification if extended life required. Consider maintenance or disposal.
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Fault identification and remedy

Simply recording failure rates and relying on final inspection to weed out faulty products treats the symptoms but not the cause, and is a waste of time and money. Eliminating failures saves money and is a design function (a mixture of product and process design).

The Best Approach Is:

- 1) Identify the cause(s) of failure, preferably before volume production begins.
- 2) Apply this knowledge to revising the design or production process.
- 3) Check that the revision has worked.
- 4) Keep records of successful reliability improvements, and carry forward the knowledge of what works by updating in-house design guidelines.

One way of identifying the cause of failure in a component or product is to make an assumption about the likely cause, change the offending parameter, and retest – a trial and error approach. For example, cracks in the neck of a welded glass light bulb are thought to be caused by insufficient time in the burner flame during manufacture, so the time the bulb spends in flame is increased, to see if this makes a difference.

Safety Critical Design:

Product reliability and safety are related. If a product is performing a safety-critical role, then failure of a key component can have dire consequences. There are several approaches to minimizing the risk of catastrophic failure:

- 1) **Over-specification:** For product applications in the building and construction industry, it is standard practice to include a 'x5' safety factor in all material strength calculations. For example: a suspension bracket for a 10kg light fitting will be designed to carry at least 50kg.*
- 2) **Redundancy (parallel):** Multiple identical components are used simultaneously, any one of which would be capable of supporting normal product function. For example, a passenger lift has 4 cables carrying the lift cabin, all sharing the load. Any one cable would be capable of carrying the full passenger lift load. A failure of up to 3 cables will not endanger the lift occupants. Flight control and instrument systems in some aircraft adopt a similar strategy. Dual wiring in military systems improves survivability.
- 3) **Redundancy (standby):** A back-up system is held in reserve and comes into operation only when the main system fails, for example stand-by generators in hospitals, and reserve parachutes. * The light fitting mentioned above might have a safety chain loosely fitted, to catch the light fitting if the support bracket fails. The chain would be an example of standby redundancy. Standby redundancy is often described as a 'belt & braces' approach.
- 4) **Fail-safe design:** Assumes an inherent risk of failure for which the cost of any of the above three strategies would be prohibitively high. The product or system is designed to drop into a safe condition in the event of partial or total failure. For example:
 - i. The gas supply to a domestic central heating boiler is shut off in the absence of a 'healthy' signal from the water pump, flame sensor, water pressure sensor, or exhaust fan.
 - ii. Toys can be designed to fracture at pre-determined weak points so as to leave no sharp projections that would injure a child.
 - iii. Railway train brakes are released by vacuum, and applied by admitting air. If a brake pipe bursts, the admitted air automatically applies the train brakes.

The 10x Rule:

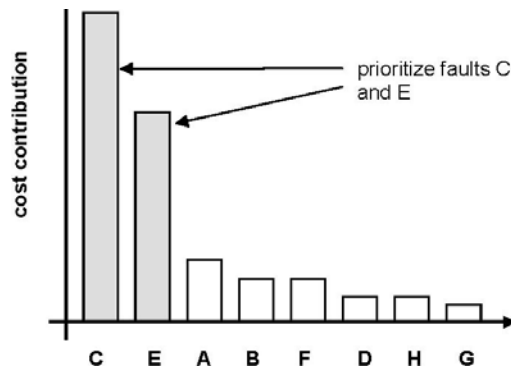
Design errors create rework costs. Errors detected during the component design phase can be corrected locally without serious impact on development times and costs. However, with each successive stage in development, the rework cost increases by a factor of ten, so that:

Stage of production	Rework costs (correcting errors)
Component design and manufacture	X 1
Prototyping and Sub-assembly manufacture	X 10
Final product assembly	X 100
Volume product shipped to dealers	X 1000
Volume product sold to customers and in use	X 10000

Thorough testing at each stage of manufacture saves costs in the long run, especially during prototype and pre-production stages.

Pareto analysis (the 80/20 rule):

The 80/20 rule is an observation that populations (of people, objects or events) can often be roughly divided into the 'vital 20%' and the 'trivial 80%'. In the context of product reliability, it is said that 20% of product faults are responsible for 80% of the failure costs. Clearly the priority is to identify this 20% and provide an early remedy. A useful tool for identifying the vital 20% is the Pareto chart, which is a simple graphical technique for displaying recorded faults. Fault rates under specific headings are tabulated, costed, converted to graphical form (usually a bar chart) and examined for individual cost contribution. The individual faults responsible for the highest costs are obviously the ones to remedy first. For example, the chart below shows the 8 most common faults appearing on a particular automobile:



Faults C and E, being the most costly, should be prioritized for remedial design work.

More Reliability Design Examples:

Reliability problem	Remedy
Leaking drain plug in central heating boiler.	Sensitivity to insertion torque and temperature tested. All plugs inserted to the newly established optimum torque. Thread locking paste used.
Fretting of rolled brass foil receptors on aircraft electric wiring connectors, giving bad connections and errors in instrument readings.	Rolled foil design replaced by expanding wire cage design, giving 'wiping' action, larger contact area and higher retention force. Gold plated to eliminate corrosion.
Frequent breaking of piston rings in aircraft engine.	Optimum piston and bore dimensions established and tolerances tightened. Engine lubrication system revised.
Vibration leading to failure in domestic fan heater.	Vibration traced to misalignment of 2 stub axles on a cylindrical fan. Replaced with a single long axle.
Car side light bulbs showing weakness at base of bulb, where bulb stem and glass envelope are melted together in a gas/air flame during manufacture.	Process tightened to give greater control over gas pressure, jet size, melt time, rotation speed. Taguchi methodology used to find optimum settings and minimize sensitivity to factory air temperature variations.
Faults in aluminum casting for electric motor (1). Voids and sand inclusions.	Sensitivity to melt temperature, mould temperature, sand moisture content, additive content, and pouring speed established. Conditions reset to optimum.
Faults in aluminum casting for electric motor (2). Warping of casting, some areas not filled.	Design of casting revised – uniform wall and rib thickness throughout. Corners rounded to improve metal flow in some areas.
Handsets on public telephones. Rising breakage rate in the field – suspected vandalism.	Handsets found to be brittle when cold. Analysis of plastic showed departure from specified grade of polycarbonate. Material supply error corrected.
Mechanical contacts (ignition points) on car prone to corrosion and in need of constant adjustment. Common cause of vehicle breakdown.	Mechanical switch points replaced with a sealed inductive device and control unit – electronic ignition.
Premature failure of pivot points in hand-operated staple tacker gun.	Soft steel case rivets were being used as pivot axles to save cost. Design revised to provide hardened sleeves over rivets at points of high wear. Rivets upgraded.
Early wear-out failure of conveyor belt end bearings (ball bearings).	Caused by shocks from heavy materials passing over end roller and by ingress of dust. The ball bearings were replaced with sealed taper roller bearings to provide a bigger load-bearing area and keep out dust.
Frequent breakage of keys in a particular type of lock, due to need for excessive force in turning key.	Lock mechanism and guide plates found to be misaligned due to inconsistent choice of datum lines on engineering drawings. Error corrected on drawings.
Faulty electric food whisks being returned to shop within 6 months of purchase. All show signs of twist in the mains cord.	Some users impart a twist to the mains cord when coiling it up. Cable entry point revised to incorporate an anti-twist cord grip and strain relief sleeve. Cordage cross sectional shape changed from elliptical to circular, to reduce potential for twisting. Molded-on plug fitted.
Expensive integrated circuit failing prematurely in data logger prototype.	Found to be a 12-volt device running on a 20-volt supply. Power supply and prototype circuit had to be redesigned to operate at 12 volts, since the IC was not available in a 20-volt version.
Vending machine faults – outdoor location at seaside. Corrosion of tracks on electronic circuits.	Circuits given conformal coating (a waterproof coating to keep out the corrosive salt-laden damp air). Connector contacts gold plated.
Filament lamps on road vehicles have short lives because of vibration and thermal shock.	Filament lamp bulbs (indicators, brake, side and rear fog lamps) all replaced with high intensity LED arrays, which have longer natural life and are less affected by thermal and mechanical shock.

Links and Resources:

For more on product reliability go to:

www.weibull.com/knowledge/pubs_index.htm

For a summary of the major quality movements, see:

http://simplesystemsintl.com/quality_gurus.htm www.dti.gov.uk/quality/5i.htm

For information on the reliability Taguchi methodology, see:

<http://kernow.curtin.edu.au/www/Taguchi/sect3.htm#Q1>

www.lmu.ac.uk/lis/imgtsev/tools/tools.htm

www.ee.iitb.ac.in/~apte/CV_PRA_TAGUCHI_INTRO.htm

www.amap.sunderland.ac.uk/cattraining/sDesign?cattraining www.dti.gov.uk/quality/5i.htm

For General Design Tips and Resources, visit:

<http://www.design1st.com/Design-Resource-Library/design-resource-center.html>