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Reducing Risk by Segmentation

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ABSTRACT

The paper provides analysis of the various mechanisms through which the segmentation improves reliability and reduces technical risk and presents a classification of risk-reduction techniques based on segmentation. On the basis of theoretical arguments and examples, it is demonstrated that segmentation increases the tolerance of components to flaws causing local damage, reduces the rate of damage accumulation and damage escalation and reduces the hazard potential. The paper also demonstrates that segmentation essentially replaces a sudden failure on a macro-level with gradual deterioration of the system on a micro-level through non-critical failures. It is demonstrated that segmentation can even reduce the likelihood of a loss from opportunity bets and the likelihood of erroneous conclusion from imperfect tests. Finally, a comprehensive classification of methods and techniques for reducing risk, based on segmentation, has been proposed.

KEYWORDS

Generic Principles, Reliability Improvement, Risk Reduction, Segmentation, Technical Risk

1. INTRODUCTION

A systematic classification of generic methods for reducing technical risk is crucial to safe operation, to engineering designs and software, yet this very important topic has been overlooked in the reliability and risk literature. For many decades, the focus of reliability research has been primarily on reliability prediction instead of reliability improvement.

Work on formulating generic principles and methods for improving the reliability of engineering components and systems has already been done in (Todinov, 2007, 2015). The generic reliability improvement and risk reduction methods and principles are especially suited for developing new designs, with no failure history and with insufficiently researched failure mechanisms. The present paper contributes an important generic reliability improvement and risk reduction method referred to as 'the segmentation method.' Segmentation is the act of dividing an entity (assembly, system, process, task, time, etc.) into a number of distinct parts. Segmentation is often combined with its antipode - aggregation. Aggregation is the act of combining a number of distinct parts into a whole.

Reducing the variation of returns by segmenting and diversifying an investment portfolio into many non-correlated stocks is a well-documented technique for reducing financial risk by segmentation. With increasing the number of non-correlated stocks, the variance (volatility) of the portfolio, which is a measure of the risk associated with the portfolio returns, is reduced significantly (Teal and Hasan, 2002).

Micro-segmentation, aimed at improving the cyber security by isolating different applications and parts of computer networks has been discussed in (Mämmelä et al., 2016).

The struggle between the need of increasing efficiency and reducing the weight of components and systems and reliability is a constant source of technical and physical contradictions. In this

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respect, the method of segmentation has been used as one of the principles for resolving technical contradictions in the development of TRIZ methodology for inventive problem solving (Altshuller, 1984, 1996, 1999). However, the formulated principle of segmentation was primarily formulated as a tool for generating inventive solutions by resolving technical or physical contradictions and not as a tool for reliability improvement and risk reduction. Some examples of patents using segmentation to improve reliability have indeed been listed in (Altshuller 1984, 1996, 2007), but no specific discussion has been provided related to the mechanisms through which segmentation actually works in increasing reliability. No discussion regarding the mechanisms through which segmentation works exist in more recent literature related to TRIZ (Terninko et al, 1998, Savransky, 2000; Orloff, 2006; Orloff, 2012; Rantanen and Domb, 2008; Gadd, 2011). The insufficient understanding why segmentation actually works does not allow reaching the full potential of this technique, particularly in the area of reliability improvement and risk reduction.

In addition, the segmentation as a problem-solving tool in TRIZ has been introduced in a rather narrow context: primarily as size segmentation or time segmentation. However, a physical division of the size is not the only instance when segmentation is present. Segmentation is also present when no physical division is done but additional boundaries with different properties are introduced in the homogeneous component. Such is the case of welding stiffening rings around an underwater pipeline, at regular intervals. The purpose of these rings is to restrict the eventual collapse of the pipeline between two welded rings, thereby minimising the extent of damage. Segmentation is present without the existence of a physical division of the whole object.

In addition, the TRIZ methodology does not consider a logical segmentation where no physical division exists yet the system is still segmented. In a logical segmentation of a computer network into several distinct parts for example, no reduction of size or complexity exists. In effect, during a logical segmentation, the barriers set between the different parts of the network increase complexity.

Essentially, the logical segmentation has been used as a very efficient problem-solving tool, long before the emergence of the TRIZ methodology and many other methodologies for creative problem solving. Segmentation is at the heart of one of the biggest inventions in mathematics - the differential and integral calculus. In determining the volume of an object with complex shape by double integration, for example, the volume is essentially converted into segments/slices with the same infinitesimal thickness and with cross-sectional area dependent on the position along one of the coordinate axes. In turn, the cross-sectional area of each slice is essentially converted into segments (multiple strips) with the same width and height dependent on the position of the strip along another coordinate axis. As a result, the evaluation of the complex volume is essentially reduced to two sequential summations (integrations) involving segments.

Another powerful problem-solving strategy based on segmentation has also been known for a long time - the divide-and-conquer strategy. This is a powerful strategy for solving seemingly intractable problems by combining segmentation and its antipode - aggregation.

The divide-and-conquer approach breaks a problem into simpler sub-problems for which solutions can be obtained with the available means. Next, the obtained solutions are aggregated (merged) until the solution of the initial problem is obtained. The divide-and-conquer approach is at the heart of the heapsort algorithm for sorting arrays of large size n, whose worst-case running time (unlike the worst-case running time of the quicksort algorithm) is always $O(n \ln_2 n)$ (Sedgwick, 1992).

Segmentation combined with aggregation is also at the heart of the decomposition method for system reliability analysis (Todinov 2007) where the initial complex system is decomposed into simpler systems upon the condition of a single key component or several key components. The resultant systems can in turn be decomposed and so on, until trivial systems with simple solutions for their reliability are obtained. The system reliability of the initial system is obtained by aggregating (combining) the system reliabilities of the obtained trivial systems. Finally, segmentation of a complex task into multiple simpler manageable sub-tasks has always been a cornerstone in managing the execution of projects.

Despite that applications of the segmentation method for reliability improvement and risk reduction have actually been used in engineering designs, no systematic analysis and classification of the various segmentation techniques and the mechanisms through which they achieve their goal currently exists. Recently, in (Todinov, 2015), it has been suggested that the method of segmentation should be used as a risk reduction tool but the method of segmentation was introduced primarily as a method for reducing the consequences of failure. No discussion has been related to reducing the likelihood of failure by segmentation. To the best of our knowledge, no work currently exists on the application of segmentation for reducing the likelihood of failure and on the mechanisms through which segmentation leads to reliability improvement and risk reduction. This paper aims to fill these gaps.

2. PREVENTING DAMAGE ACCUMULATION AND LIMITING DAMAGE ESCALATION BY SEGMENTATION

Segmentation often creates physical boundaries which serve as barriers delaying damage accumulation. Since many failures are initiated when the damage accumulates beyond a critical level (e.g. fatigue failure), segmentation can be often be used to delay the failure occurrence. Delaying damage accumulation essentially reduces risk of failure by reducing the likelihood of failure associated with a specified time interval.

Segmentation to a very small size (e.g. spinning very thin glass fibers) simply does not allow for an imperfection to be present and this is another mechanism through which segmentation prevents accumulation of damage and decreases the likelihood of failure.

The physical boundaries created by the segmentation also prevent the escalation of damage, which is another distinct mechanism through which segmentation reduces the risk of failure - by reducing the consequences given that failure has occurred.

2.1. Creating Barriers by Segmentation

The boundaries created by segmentation can be used to block the pathways through which the damage accumulates or to delay the spread of damage. The boundaries introduced by the segmentation act as passive protective barriers, physically separating the hazards (the energy sources) and isolate and contain the consequences in case of an accident. Space segmentation by introducing blast walls reduces the damage from blast waves and is an efficient measure against domino-type failures of fuel tanks and pressure vessels built in close proximity. The boundaries created by the segmentation provide passive protection against the spread of fire, radiation, toxic substances or dangerous operating conditions.

The boundaries resulting from the segmentation prevent damage from building to a critical level which precipitates failure. The Hall-Petch relationship for example, has been known for a long time in physical metallurgy. This is a relationship between the yield strength σ_y of a material and the average grain diameter d.

$$\sigma_y = \sigma_0 + \frac{k_y}{\sqrt{d}} \tag{1}$$

where σ_0 and k_y are material constants. This relationship holds for grain sizes ranging from 1mm to 1 μm. With increasing the degree of segmentation, which is equivalent to reducing the grain diameter and increasing the number of grains, the yield strength σ_y increases. The increase of yield strength increases the relative separation between the load distribution and the strength distribution which improves reliability (Todinov, 2007). In polycrystalline materials, plastic deformation is due to the movement of dislocations through the material. The smaller the grain size, the larger is the stress necessary to propagate the dislocations through the grain boundaries. As a result, segmentation achieved through grain refinement has been used to increase the strength of materials and reduce the risk of failure.

It needs to be pointed out, that the boundaries resulting from segmentation increase strength in cases where they limit the accumulation and escalation of damage. The boundaries can also be a weakness if the damage accumulates and spreads along them. Such is the case in grain boundary embrittlement for some materials. This is often caused by an oxidation, corrosion and inappropriate heat treatment resulting in a segregation of harmful impurities and weak phases along the grain boundaries. Weakened grain boundaries reduce the energy of intergranular crack propagation and increase the risk of failure.

The boundaries from segmentation often help reduce the damage escalation and the consequences given that failure has occurred. Thus, segmenting a pipe into many separate sealed segments limits the damage from a propagating crack within a single segment only, which reduces significantly the consequences from failure.

Segmentation limiting the damage escalation can be used for reducing technical risk in a wide range of applications. It has been used effectively to increase the resistance of a ship to flooding. The volume of the hull is divided into watertight compartments. If flooding is localised, only a single or few compartments are affected, which allows the ship to retain buoyancy. Space segmentation of the corridors in a building, with fireproof doors has been used to delay the spread of fire.

Segmenting large formations of people into smaller groups has been used to prevent the spread of infectious diseases. Valuable assets can be protected by reducing the amount of accessed asset.

Segmentation of computer networks also limits the spread of damage and has clear security benefits. For a segmented computer network, accessing a computer in one segment does not automatically give the attacker an easy access to other segments. A segmented network design can significantly slow the rate at which an attacker moves towards the valuable service and provides more opportunities for a successful detection. In addition, securing each segment through firewalls makes accessing the valuable service much more difficult because numerous security walls must be breached before an access can be gained. The result is a significantly reduced likelihood of unauthorised access.

2.2. Improving Fault Tolerance by Segmentation

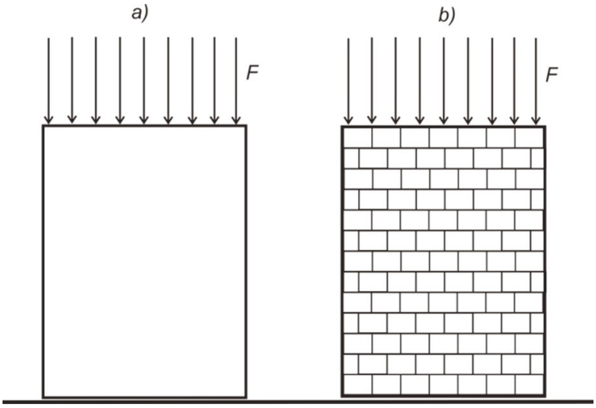
A common failure mechanism is a locally initiated damage which spreads to cause a total collapse of a component or structure. Segmentation can be used to improve the resistance to a local damage which subsequently spreads and causes total collapse. Ropes and cables are typical segmented structures built of multiple twisted strands or wires. The segmented design does not allow the local damage from failure of a single strand to penetrate into the neighbouring strands.

A monolithic glass panel will shatter totally if hit by a projectile because the initial crack from the projectile spreads through the entire panel. Segmenting the glass panel into small glass bricks makes the panel resistant to a local damage. A glass panel made of small glass bricks will suffer only a local damage but will not shatter totally. The segmentation prevents a crack appearing in one segment to penetrate another segment and extend. As result, the local failure of a glass brick does not transcend into a failure of the panel. The same effect is present for walls built with stones and bricks.

To demonstrate theoretically that segmentation indeed improves fault tolerance, suppose that $\lambda_1(\sigma)$ is the number density of flaws in a monolithic cylindrical column with volume *V,* subjected to a compression (Figure 1a). A critical flaw is a flaw which, if present in the column, will initiate an unstable crack which propagates through the material of the column. In the case of a monolithic column, a critical flaw will cause failure of the column.

Suppose that the flaws follow a homogeneous Poisson process in the volume of the column and the probability that a flaw will be critical is $F_c(\sigma)$. For example, the probability $F_c(\sigma)$ that a flaw will be critical can be thought as the probability $F_c(\sigma) = P(D \geq d_c(\sigma))$ that the diameter ***D*** of the

Figure 1. Segmentation improves the fault tolerance



flaw will be greater than a particular critical value $d_c(\sigma)$, dependent on the loading stress σ in the material, caused by the distributed forces *F* (Figure 1a).

The probability of failure p_f of the column at a loading stress σ is now equal to the probability that at least a single critical flaw will be present in the stressed volume of the loaded column. According to an equation derived in (Todinov, 2005), this probability is given by

$$p_f = 1 - \exp\left[-\lambda_1\left(\sigma\right)F_c\left(\sigma\right)V\right] \tag{2}$$

If the maximum acceptable probability of failure of the column has been specified to be p_f, the maximum acceptable number density of the flaws in the material of the monolithic column can be determined:

$$\lambda_1(\sigma) = -\frac{1}{F_c(\sigma)V}\ln\left(1 - p_f\right) \tag{3}$$

Now suppose that the column has been segmented into *n* bricks with the same volume V_b and made of the same material (Figure 1b). Because of the bricks boundaries, a crack starting from a critical flaw in any of the bricks now cannot spread through the entire column and cause collapse of the column. It only causes failure of the brick where the flaw resided. Because of the segmentation of the column, suppose that a collapse of the column occurs only if a certain fraction p_b of failed (cracked) bricks are present in the column. The maximum tolerable probability of failure of a brick in the column is therefore also equal to p_b.

Assume that for each brick, the probability that a flaw in the brick will be critical (will cause failure of the brick) is equal to $F_c(\sigma)$. Again, the probability that a flaw in the brick will be critical can be thought as the probability $F_c(\sigma) = P(D \geq d_c(\sigma))$ that the diameter *D* of the flaw will be greater than a particular critical value $d_c(\sigma)$ dependent on the loading stress σ. The maximum acceptable probability of failure of a brick can now be related to the maximum acceptable number density of flaws $\lambda_2(\sigma)$ in the bricks:

$$p_b = 1 - \exp[-\lambda_2(\sigma) F_c(\sigma) V_b] \tag{4}$$

Solving this equation with respect to $\lambda_2(\sigma)$ gives:

$$\lambda_2(\sigma) = -\frac{1}{F_c(\sigma) V_b} \ln(1 - p_b) \tag{5}$$

for the maximum acceptable number density of the flaws in the material of the bricks.

Taking the ratio of equations (5) and (3) gives:

$$\frac{\lambda_2(\sigma)}{\lambda_1(\sigma)} = \frac{V}{V_b} \times \frac{\ln(1 - p_b)}{\ln(1 - p_f)} = n \frac{\ln(1 - p_b)}{\ln(1 - p_f)} \tag{6}$$

where $n = V / V_b$ is the number of the bricks. For the specific values $p_f = 0.001$, $p_b = 0.03$ and $n = 300$ bricks,

$$\frac{\lambda_2(\sigma)}{\lambda_1(\sigma)} = 300 \times \frac{\ln(1 - 0.03)}{\ln(1 - 0.001)} \approx 9 \times 10^3$$

As a result, in case of a segmented structure, the maximum tolerable number density of the flaws in the material of the bricks can be many orders of magnitude higher than the maximum tolerable number density of the flaws in the material of the monolithic column. Segmentation increased significantly the fault tolerance.

2.3. Reducing Strains by Segmentation

Damage appearing as an excessive deformation can be significantly reduced by segmenting a process associated with a large amount of energy into intermediate processes, each associated with a much smaller amount of energy. The result is a greater control, minimal intermediate deformations, minimal total deformation and minimal risk of failure.

For example, instead of applying the full thermal load in a single weld bead, the single weld bead can be segmented into several smaller multi-pass welds. Each of the smaller welds introduces a smaller amount of thermal energy and the result is a significantly reduced geometric distortion of the welded part compared to welding with a single pass and large energy.

Thermal deformations can also be reduced by a geometrical segmentation which consists of segments separated by expansion gaps. Thus, the thermal expansion gaps left between rail segments and between building panels helps to accommodate thermal expansion strains and reduce the thermal stresses whose magnitudes would otherwise be capable of destroying the structures.

2.4. Reducing the Hazard Potential by Segmentation

2.4.1. Limiting the Amount of Energy Possessed by Hazards

Segmentation of hazardous substances can be applied with success to limit the amount of energy locked in the substance and its potential to cause harm. Processing very small (segmented) volumes of toxic substances at a time, for example, significantly reduces the hazard potential of the handled substance and eliminates the risk of poisoning in case of accidental spillage.

Preventing the formation of large build-ups of snow, water, overheated water vapour etc., by a physical segmentation, reduces both the likelihood of accidental release of a large amount of potential energy and limits the extent of damage/destruction should an accident occur.

Segmentation of hazardous substances avoids steps that could potentially cause harm and is fully in line with the ‘precautionary principle’ in risk management (Sunstein, 2002). What makes this risk reduction technique particularly appealing is that it does not require external factors to achieve risk reduction. Risk reduction is achieved within the current system, without the involvement of auxiliary resources. As a result, the segmentation method does not involve a big investment to reduce risks and leads to very economical risk reduction solutions. Handling a limited quantity of harmful substance at a time does not involve significant investment but does guarantee that the potential harm will be small. Unlike implementing some other risk reduction measures, segmentation, does not lead to indefensibly big expenses exhausting the safety budgets.

2.5. Limiting the Presence of Flaws by Segmentation

Segmentation of materials, resulting in very small volumes, does not allow for an imperfection to be present. This is the one of the reasons for the exceptional strength of glass fibers and carbon fibers, for example.

Glass fibers are spun from molten glass and are with diameters between 10 and 100 microns. The absence of imperfections, because of the very small cross sections, contributes to their exceptional tensile strength. Because of their exceptional strength, they are used for reinforcement in glass fiber polymers.

Carbon fibers are very thin (< 10 microns in diameter) and also possess exceptional tensile strength due to the very small sections and the absence of imperfections. They are commonly woven into textiles and used as reinforcement in polymer, metal or carbon matrices (Ashby and Jones, 2002).

3. REDUCING LOADING STRESS BY SEGMENTATION

3.1. Increasing Contact Area by Segmentation

Segmenting a component into several smaller components increases the contact area and often brings a significant reduction of the maximum stresses. The reliability increase is achieved by distributing the load upon many load-carrying units.

In cases where torque is transmitted from a rotating shaft to a gear, sprocket or pulley or vice versa, retention devices such as keys or splines are used to prevent the relative rotation of the gear, sprocket or pulley. For a specified torque, the stresses acting on a single key are high because the load is concentrated over a relatively small area. Splines can essentially be regarded as segmented keys, uniformly spaced around the shaft. The segmentation in this case, improves the load distribution, decreases the stresses and ensures a higher reliability of the connection for a given magnitude of the torque.

In another example, consider a flange with very few fasteners. A flange connection with a very small number of fasteners leads to excessive stresses in some of the fasteners. Segmentation involving an increased number of fasteners whose combined tensile strength is equivalent to the tensile strength of the few fasteners, improves the load distribution and improves the reliability of the assembly.

Segmentation often results in better conforming contact surfaces, with increased contact area and significantly reduced contact stresses. Segmentation increases the contact surface or the length of contact line thereby reducing the contact stresses. Reduced contact stresses result in reduced wear and increased reliability. For example, segmentation which consists of introducing several rows of ball bearings, instead of a single row, reduces significantly the contact stresses and wear of the ball bearings.

3.2. Reducing the Tensile Stresses in Pressure Vessels by Increasing the Perimeter to Cross-Sectional Area Ratio by Segmentation

Segmentation reduces loading stresses by increasing the perimeter to cross-sectional area ratio. This rather subtle yet very powerful segmentation effect has been depicted in Figure 2a featuring a pressure vessel with volume *V*, and thickness *t* of the shell. The pressure vessel contains fluid exerting pressure *p* on the inside of the shell (Figure 2a). Segmenting the vessel into *m* smaller and similar pressure vessels with volumes V_1, V_2, ..., V_m (Figure 2b) ($V = V_1 + V_2 + ... + V_m$), reduces significantly the maximum stress acting in the shell of each of the smaller vessels.

Indeed, an expression for the stress acting in the wall of the pressure vessel can be derived from the equilibrium of elementary forces. A slice has been taken from the pressure vessel (Figure 3). The *z*-axis is perpendicular to the *x* and *y* axes.

The pressure *p* is always perpendicular to the wall of the pressure vessel (Figure 3). The elementary force created by the pressure *p* on an elementary surface area *ds* on the inside wall of the vessel is equal to $p\,ds$. The component of this elementary force along the *y*-axis is $(pds) \times \cos\alpha$ where α is the angle which the normal to the elementary surface element subtends with the *y*-axis (Figure 3). Note that the projection of the elementary force can also be written as a product of the pressure *p* and the projection of the elementary area $ds\cos\alpha$ on the (*x, z*)-plane. The sum of the components of all elementary forces along the *y*-axis, due to the internal pressure *p*, is therefore given by the product pS of the pressure *p* and the total projected area S of the inner surface of the pressure vessel on the (*x, z*)-plane. This resultant force must be counterbalanced by the sum of the forces $tL\sigma_S$ created by the stress σ_S acting in the wall of the pressure vessel, where *t* is the thickness of the shell

Figure 2. Segmenting the pressure vessel into several smaller pressure vessels increases the perimeter to cross-sectional area ratio and significantly reduces the loading stress acting in the wall

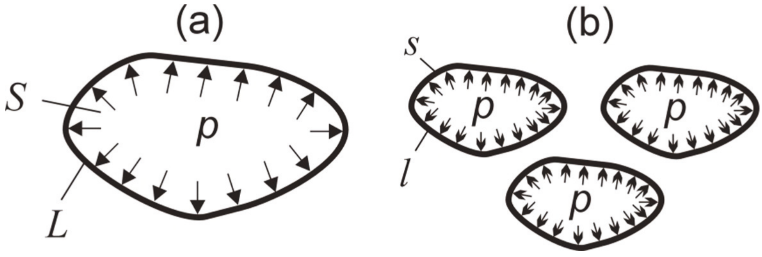
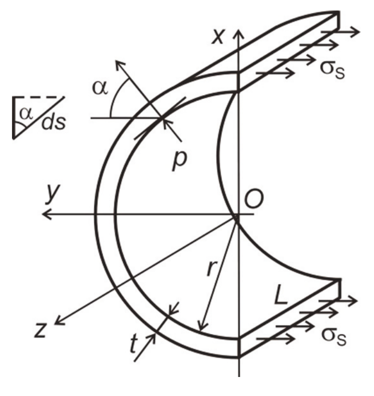


Figure 3. Derivation of the magnitude of the stress acting in the shell of a vessel under pressure with magnitude p



and L is the perimeter of the sliced part of the pressure vessel along which the counteracting stress σ_S acts (Figure 3). Suppose that *S* is the projected area of a selected section from the initial pressure vessel and *L* is the perimeter of that section. Denote by *s* and *l* the projected area and the perimeter of the similar cross section from the smaller pressure vessel.

From the equilibrium equation $tL\sigma_{S0} = pS$, the expression

$$\sigma_{S0} = \frac{pS}{tL} \tag{7}$$

is obtained immediately for the stress acting in the wall of the large pressure vessel. Similarly,

$$\sigma_{S1} = \frac{ps}{tl} \tag{8}$$

is obtained for the stress acting in the wall of the smaller pressure vessel. With reducing the size of the pressure vessel by segmentation, the ratio of the cross section area and the perimeter of the cross section decreases:

$$\frac{s}{l} < \frac{S}{L} \tag{9}$$

Since the pressure *p* and the thickness *t* of the wall are not altered by the segmentation, from equations (9), (7) and (8), it follows that $\sigma_{S1} < \sigma_{S0}$. Consequently, segmenting a pressure vessel with arbitrary shape into smaller similar pressure vessels reduces the loading stresses in the wall.

The degree of reduction of the loading stresses will be illustrated with a simple special case of a spherical pressure vessel with inner diameter *D* and thickness of the shell *t*, subjected to a pressure with magnitude p. The cross sectional area of a section across the centre of the spherical vessel is $S = \pi D^2 / 4$ and the perimeter of the cross section is $L = \pi D$. If the initial pressure vessel is segmented into a number of pressure vessels with inner diameter *d*, for the ratio of the loading stresses in the wall, the expression

$$\frac{\sigma_{S0}}{\sigma_{S1}} = \frac{D}{d} \tag{10}$$

is obtained from equations (7) and (8). If the initial pressure vessel is segmented into pressure vessels with twice as small diameter, the maximum loading stress in the wall, due to the pressure *p*, is halved.

This example demonstrated that by increasing the perimeter to cross-section area ratio, segmentation reduces significantly the magnitude of the stresses in pressure vessels.

Often segmentation is used to achieve a greater level of balancing. The increased level of balancing results in a greater stability and smaller vibration amplitudes which enhances reliability. Such is for example the case of introducing multiple cylinders in internal combustion engines, multiple blades in a turbine, etc.

3.3. Improving Heath Dissipation by Segmentation

Segmentation increases the total surface area of the segmented parts, which helps heat dissipation. Heat dissipation is an important aspect of the reliability of electronic devices. Fast heat dissipation and an equilibrium temperature within the acceptable limits is a necessary condition for a fault-free operation of many electrical components. For a given volume of the component, segmentation increases the surface area through which heat is lost and the component is cooled. An increased heat transfer means a low equilibrium temperature and more reliable operation. If a segmentation of the heated components is not possible, highly segmented radiators attached to the components are used for fast heat dissipation.

Heat dissipation is also an important aspect of the reliability of mechanical devices. In mechanical systems, an example can be given with a single *V*-belt, segmented into multiple parallel *V*-belts. Because of the segmentation, the heat released due to hysteresis losses is better dissipated by multiple parallel *V*-belts. Better heat dissipation leads to a lower equilibrium temperature of the material of the belt and enhanced reliability.

4. REDUCING THE VULNERABILITY TO A SINGLE FAILURE BY SEGMENTATION

Segmentation reducing the risk of unauthorised access to a valuable asset has been practiced in cases where the valuable assets are divided (segmented) into smaller parts, each of which is subsequently stored in a different place. Accidental access to a part of the asset will not result in an automatic loss of the entire asset. Segmenting a single command centre into a mesh-type network of interconnected parts makes the command centre invulnerable to a single strike.

4.1. Reducing the Vulnerability to a Single Failure by Segmentation

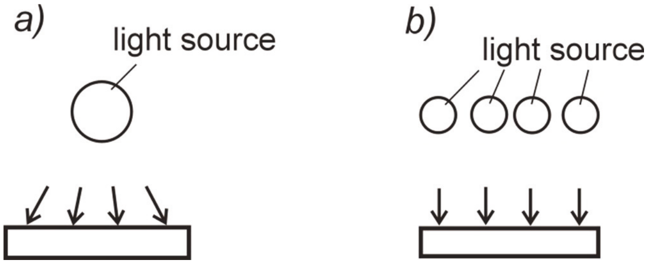
Segmentation replaces a single critical failure occurring at a macro level with non-critical failures occurring at a micro level. Suppose that a single light source is used for illuminating a critical manufacturing process. Failure of the light source entails an interruption of the manufacturing process and causes severe delays and lost production. If the single light source is segmented into multiple smaller light sources with the same total luminous flux, failure of a single lamp or even failure of half the lamps will not be catastrophic and will not entail a shutdown of the manufacturing process. Segmentation reduces risk by replacing a single critical failure at a macro level with non-critical failures at a micro-level. This essentially replaces a sudden failure at a macro-level with gradual deterioration of the system at a micro-level through many non-critical failures.

Analytical justification of this technique will be given with the single light source used for illuminating a critical spot on a manufacturing line in Figure 4a whose reliability associated with one year of continuous operation is $r = 0.75$. Suppose that a segmentation of the light source has been made by replacing it with four smaller light sources which give the same total luminous flux as the single light source. Each of the smaller light sources is characterised by a lower reliability $s = 0.70$, associated with the operational time interval of one year. Any two of the smaller light sources are sufficient to perform the function of illuminating the critical spot on the manufacturing line.

The probability that the segmented light assembly will survive 1 year of continuous operation without having to shut down the manufacturing line because of lack of sufficient illumination, is now equal to the probability that at least two (two, three or all four) light sources survive the operational interval of one year. If the light sources fail independently from one another, this probability is given by

$$R = s^4 + \frac{4!}{3!\times(4-3)!} s^3 (1-s)^1 + \frac{4!}{2!(4-2)!} s^2 (1-s)^2 = 0.916 \tag{11}$$

Figure 4. Segmentation reduces the vulnerability to a single failure



As a result of the segmentation, the reliability of the segmented assembly increased significantly compared to the single light source, despite that the reliability of the smaller light sources in the segmented assembly was actually inferior to the reliability of the single light source.

Similarly, for a flange with a very few fasteners, failure of any single fastener will cause a loss of containment. In other words, every single failure of a fastener is critical. Consider now a flange with many fasteners, each of which has a lower reliability and lower load-carrying capacity compared to the original fasteners. This assembly will not be vulnerable to a single failure of a fastener or even to several failures. The single critical failures in the initial assembly have been replaced by non-critical failures in the segmented assembly. The sudden failure has been replaced by gradual deterioration.

A very similar case exists for the failure of a solid steel rod and the failure of the segmented rod into a cable with the same strength, built by twisting a large number of wires. The critical failure of the solid rod on a macro-level has been replaced by non-critical failures of the twisted wires on a micro-level. Instead of a sudden failure, the segmented cable will experience gradual deterioration through the non-critical failures of the separate wires. When the inspection discovers that the number of failed single wires at the surface becomes greater than a specified maximum tolerable quantity, the cable will be replaced and the catastrophic consequences from a sudden failure will be avoided.

The segmentation method also greatly enhances the reliability of devices obtaining a signal from a sensor and triggering a particular action/alarm if the signal indicates a dangerous concentration of a particular chemical, dangerous magnitude of a force, torque, pressure, temperature, humidity, etc. Segmentation of a single sensor into multiple sensors, even with inferior reliability, makes the device less vulnerable to a malfunction of a sensor or even to simultaneous failures of several sensors.

4.2. Reducing the Vulnerability to Failures by Creating a Reconfigurable System Through Segmentation

Segmenting an assembly into a number of identical sections makes the assembly easily reconfigurable if one or several sections are damaged. For example, a long chute on a building site, made of separate small segments which fit into each other, can be easily damaged by the transported building debris. The segmented chute however, can be reconfigured easily into a fully functioning chute by simply discarding the damaged segment. There exist also segmented robotic systems which reconfigure themselves automatically upon failure of any of their building segments. This is done by bypassing the failed segment, with insignificant loss of functionality (Paley, 2010).

5. REDUCING THE PROBABILITY OF A LOSS/ERROR BY SEGMENTATION

5.1. Reducing the Likelihood of a Loss by Segmenting Opportunity Bets

Segmentation can also be used with success to reduce the risk of a loss from a risk-reward bet. Risk-reward events/bets can materialise as benefit or loss. An investment in a particular enterprise is a typical example of a risk-reward bet. A successful investment is associated with returns (benefits) while an unsuccessful investment is associated with losses.

Suppose that $0 \le p_s \le 1$ is the probability that the risk-reward bet will be a 'success' and $p_f = 1 - p_s$ is the probability that the risk-reward bet will materialise as a loss.

The expected values of the benefit and the loss given that the risk-reward event has materialised are denoted by $\bar{B}_s$ and $\bar{C}_f$, respectively.

The expected profit $\bar{G}$ from a risk-reward bet is then given by:

$$\bar{G} = p_s \times \bar{B}_s + p_f \times \bar{C}_f \tag{12}$$

where p_s is the probability of a beneficial outcome with expected magnitude $\bar{B}_s$ and $p_f = 1 - p_s$ is the probability of a loss with expected magnitude $\bar{C}_f$ (the loss $\bar{C}_f$ has been taken with a negative sign). If $\bar{G} > 0$, the risk-reward bet will be referred to as opportunity bet.

Traditionally, the maximum expected profit criterion is often used for making an optimal choice among risky prospects containing risk-reward bets (Moore 1983; Denardo, 2002). According to this criterion, a rational decision maker compares the expected profits from a number of risky prospects and selects the prospect with the largest expected profit.

The maximum expected profit criterion however does not account for the significant impact of the actual number of risk-reward events/bets in a risky prospect. The critical dependence of the choice of a risky prospect on the number of risk-reward bets in it has not been discussed in studies related to ranking risky alternatives (Richardson and Outlaw, 2008, Nielsen and Jaffray, 2006; Starmer, 2000). Even in a recent, probably the most comprehensive treatise of the theory of betting (Epstein 2009), no discussion has been provided on the impact of the limited number of risk-reward bets on the choice of a risky prospect. The number of risk-reward bets in a risky prospect however, has a crucial impact on the choice of a risky prospect and cannot be ignored.

The potential profit *G* from a risk-reward bet is a random variable following a Bernoulli distribution with parameter p_s. For constant values of the benefit given success $\bar{B}_s$ and the loss given failure $\bar{C}_f$, the probability distribution of the potential profit *G* is given by $P(G = \bar{B}_s) = p_s$ and $P(G = \bar{C}_f) = p_f$. The probability distribution of the potential profit *G* can be considered to be a distribution mixture including two distributions with means $\bar{B}_s$ and $\bar{C}_f$ and variances $V_1 = 0$ and $V_2 = 0$, sampled with probabilities $p = p_s$ and $1 - p = p_f$. Consequently, from the theory of the distribution mixtures (Todinov, 2007), for the variance of the potential profit we have

$$Var(G) = p_s p_f (\bar{B}_s - \bar{C}_f)^2 \tag{13}$$

The next example involves two risky prospects containing a different number of opportunity bets. The first risky prospect contains a single opportunity bet with parameters: $p_s = 0.3$, $\bar{B}_s = 300$, $p_f = 0.7$, $\bar{C}_f$ = -90 and expected profit $E(G) = 0.3 \times 300 - 0.7 \times 90 = 27$. The probability of a net loss from this risky prospect is 70%. The risk of a net loss is $-0.7 \times 90 = -63$.

The second risky prospect contains three opportunity bets with the same probability of success and failure but with three times smaller magnitudes for the benefit given success and the loss given failure: $p_s = 0.3$, $\bar{B}_s = 300 / 3 = 100$, $p_f = 0.7$, $\bar{C}_f = -90 / 3 = -30$. The expected profit from the risky prospect containing the three segmented opportunity bets is

$E(G_{123}) = 3 \times (0.3 \times 100 - 0.7 \times 30) = 27$. Because a net loss from the second risky prospect can be generated only if a loss is generated from every single segmented bet, the probability of a net loss from the second risky prospect is $p_{f,123} = 0.7^3 \approx 0.34$.

Clearly, the second risky prospect involving segmented opportunity bets is to be preferred to the first risky prospect. Segmenting the opportunity bets significantly reduced the risk.

This example shows how the risk associated with an opportunity bet can be reduced significantly if the opportunity bet is segmented (split) into several opportunity bets characterised by the same probability of success and failure as the original bet but with proportionally smaller benefit and loss. Indeed, consider a risky prospect containing a single opportunity bet, characterised by a probability of success p_s, benefit given success $\bar{B}_s$, probability of failure p_f and loss given failure $\bar{C}_f$. This opportunity bet can be segmented into *m* opportunity sub-bets, each characterised with the same probability of success and failure p_s and p_f and with *m* times smaller expected benefit and loss $\bar{B}_s / m$ and $\bar{C}_f / m$. The expected profit from the segmented bets is:

$$E(G_{1,\dots,m}) = m \times (p_s \bar{B}_s / m + p_f \bar{C}_f / m) = E(G) \tag{14}$$

is equal to the expected profit from the original bet. Considering equation (13), the variance

$$V\left(G_{1,\dots,m}\right) = \sum_{i=1}^{m} V_i = \sum_{i=1}^{m} p_s p_f \left(\bar{B}_s / m - \bar{C}_f / m\right)^2 = \frac{1}{m} p_s p_f \left(\bar{B}_s - \bar{C}_f\right)^2 \tag{15}$$

of the profit from the risky prospect with *m* opportunity bets is *m* times smaller than the variance $p_s p_f (\bar{B}_s - \bar{C}_f)^2$ of the profit characterising the initial opportunity bet.

As a result, segmenting the initial opportunity bet significantly reduced the risk of a loss. This example also shows that the number of the risk-reward activities should be a key consideration in selecting a risky prospect.

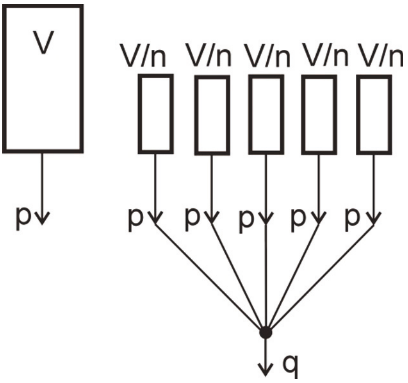
5.2. Reducing the Likelihood of an Erroneous Conclusion from Imperfect Tests by Segmentation

Another important application of the segmentation method can be found in reducing the likelihood of erroneous conclusion from an imperfect test.

Suppose that a test results either in a positive or negative outcome about the presence of a particular attribute in the test substance. The test is not perfect and produces an error with probability *p*. However, the probability of an erroneous conclusion can be reduced by segmenting the available test substance and conducting separate tests with the segmented parts instead of performing a single test with the entire available substance (Figure 5).

Suppose that each test with the segmented test substance, results in an error, with probability *p*. After all outputs from the separate tests become available, the presence of the attribute is decided by the prevalent outcome (positive or negative) from the individual tests with the segmented substance. In order for the segmented test to produce an erroneous conclusion, more than half of the separate tests must result in an error. For the special case of $n = 2k + 1$ identical tests with the segmented substance, at least *k+1* test results must be erroneous. Because the tests are statistically independent and the probability of erroneous conclusion in each test is constant, the conditions for a binomial experiment are fulfilled and the number of erroneous outputs *X* follows the binomial distribution. The probability that the number or erroneous outputs will be greater than or equal to *k+1* is given by:

Figure 5. Segmenting the available substance and conducting multiple parallel tests with the segmented parts significantly reduces the probability of an erroneous conclusion from imperfect tests



$$P(X \geq k+1) = 1 - P(X \leq k) = q = 1 - \sum_{x=0}^{k} \frac{n!}{x!(n-x)!} p^x (1-p)^{n-x} \tag{16}$$

For $n = 11$ and $p = 0.1$ for example, the probability of an erroneous output from the segmented tests is

$$P(X \geq 6) = q = 1 - \sum_{x=0}^{5} \frac{n!}{x!(n-x)!} 0.1^x (1-0.1)^{n-x} = 0.0003 \tag{17}$$

As a result, the relatively high probability of an erroneous output of $p = 0.1$ characterising the initial single test has been decreased 333 times by segmenting the test.

The same segmentation technique can be applied in taking the correct decision about approving a particular decision, transaction etc. If the process of decision making is split between a number of independent decision makers, the likelihood of making a wrong decision can be reduced significantly.

6. REDUCING THE COST OF REPLACEMENT, THE DOWNTIME FOR REPAIR AND THE TROUBLESHOOTING TIME BY SEGMENTATION

The life of a component can be extended by segmenting it into replaceable sections. This creates the possibility to replace a failed section without having to replace the entire component.

In mechanical systems for example, this technique produces maximum benefit if zones subjected to intensive wear are identified and subsequently segmented into replaceable sections. Changing a worn out replaceable section avoids replacing the entire component.

The life of a conveyor belt carrying tiles for polishing for example, can be increased significantly by applying this method. After a number of years of continuous operation of the production line, the surface of the conveyor belt will be eroded by the abrasive action of the tiles. To avoid a replacement of the entire conveyor belt, the surface zones of the conveyor belt which are in direct contact with the polished tiles, are designed as replaceable segments. As a result, instead of replacing the expensive conveyor belt, only the surface segments, which undergo the most intensive wear, are replaced or repaired (for example, by restoring the worn rubber substrates on the replaceable steel segments). This technique has also been used widely in replacing inserts for journal bearings and pads for friction brakes.

Segmenting a complex device into separate blocks, greatly reduces the downtime for repair, because such a device is easy to disassemble and assemble. Identifying the block where failure occurred is also easy and the failed block is quickly replaced with a new block without having to dismantle the entire device. The reduced downtime for repair increases the availability and efficiency of the production process.

The logical segmentation of critical information into categories and classes decreases significantly the time for retrieval of a key piece of information. This is of particular importance during troubleshooting, when a correct decision must be made very quickly, in order to avert an accident or minimize the consequences from an accident.

7. DECREASING THE VARIATION OF PROPERTIES BY SEGMENTATION

It is a well-known fact from statistics that replacing a single measurement characterised by a variance σ^2 with the average from *n* measurements, each of which is characterised by a variance σ^2, decreases the variance of the averaged result to σ^2 / n.

A coarse microstructure composed of two microstructural constituents, *A* and *B* (Figure 6a) is associated with big variation of the properties of the sample (transect) *T*.

If the segmentation of the microstructure from Figure 6a is increased (Figure 6b) by fragmenting the microstructural constituent *B*, the variation of properties of the sample (transect) *T* is decreased.

One of the reasons for the decrease in the variation of the properties of the sample is the decreased variation of the intercepted volume fraction from microstructural constituent *B* with increasing the segmentation of the microstructural constituent *B*. Figure 6c depicts the decrease of the variance of the intercepted volume fraction from microstructural constituent *B*, with increasing the size of the transect (sample).

8. REDUCING WEIGHT WITHOUT COMPROMISING RELIABILITY BY SEGMENTATION

Segmentation can often be used to resolve a major common technical contradiction - reducing the weight of designs without significantly reducing their reliability. This can be done by segmenting components into light segments connected with light joints. Segmenting a heavy beam into a light truce formed by light straight members connected through joints is a demonstration of this technique.

This technique can also be applied by segmenting components into working zones, linked with light bridges, which take directly the contact stresses and wear. This method can be used in packaging

Figure 6. With increasing the microstructural segmentation, the variation of the sample properties decreases

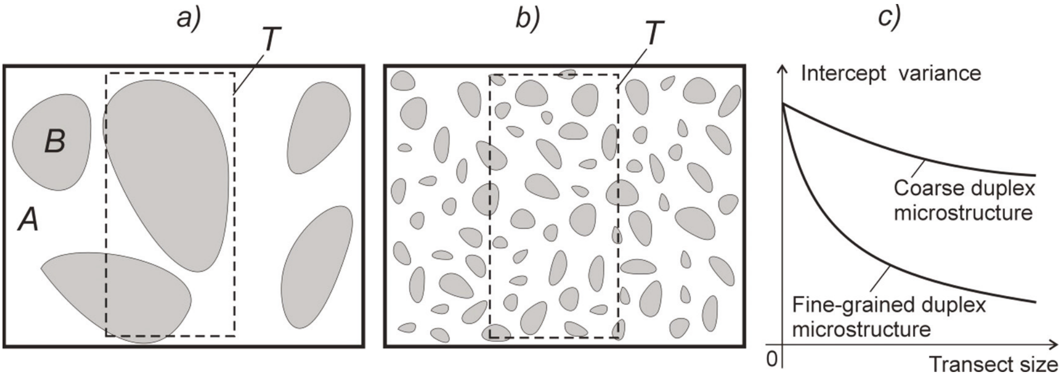
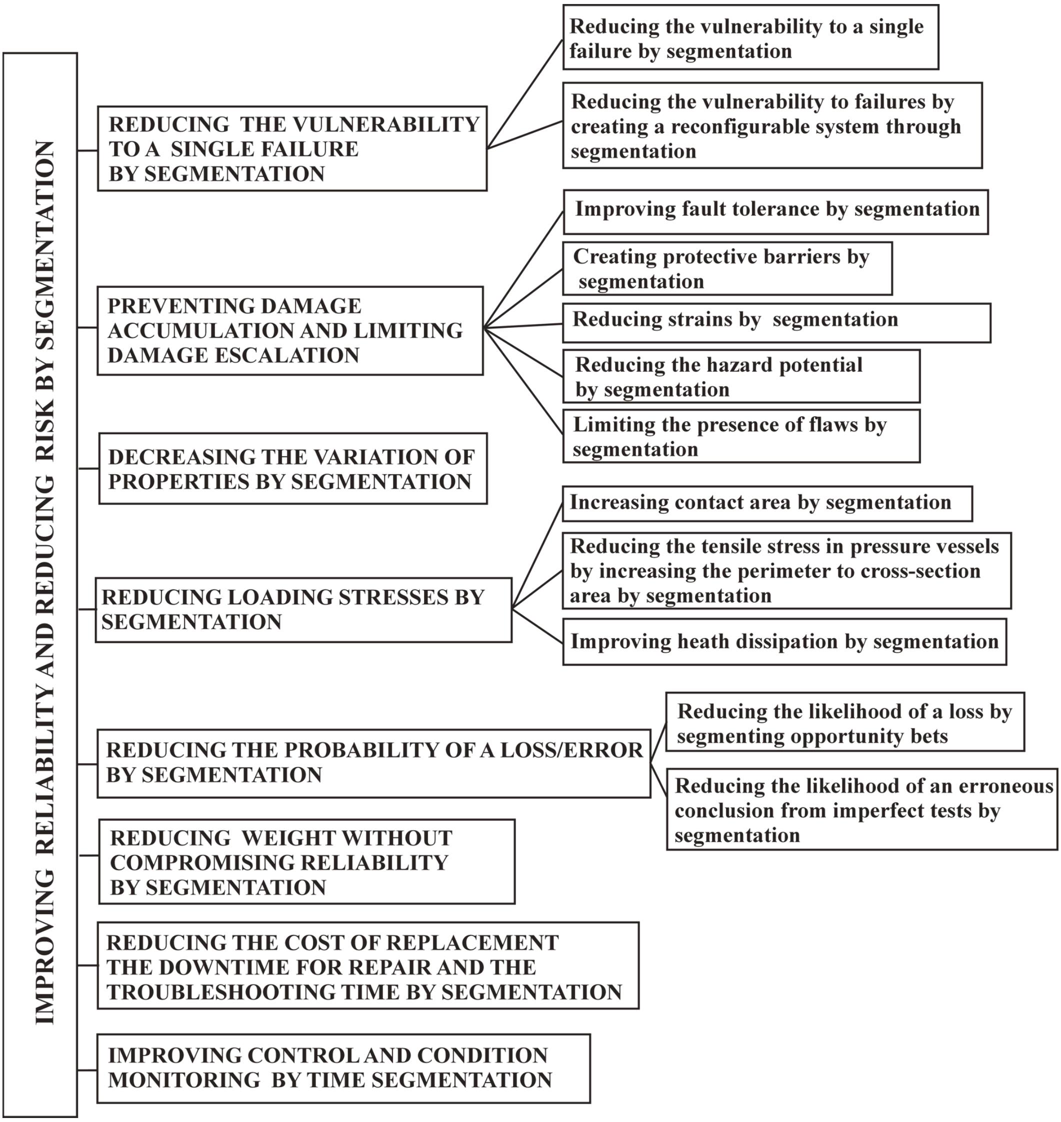


Figure 7. Classifications of various techniques for improving reliability and reducing risk by segmentation



of goods where, instead of heavy packaging boxes, only packaging segments along the edges of the packaged items are used, connected with light links. This method is used whenever a heavy monolithic foundation is replaced with multiple lighter foundation segments providing the necessary support.

9. IMPROVING CONTROL AND CODITION MONITORING BY TIME SEGMENTATION

Time discretization (segmentation) has been used with success for real-time control of various risks, for example the risk of flooding. At regular time slices (segments), a data acquisition system based on sensors, serial interface and computer, monitors key risk parameters like on-site water level, flow, rainfall, etc. and after post-processing, estimates the risk of flooding (Zhang, 2012).

Time segmentation can also be used for analysing complex motion even if the laws of motion are not known in their integral form. Such is for example the case of tracing the trajectory of a flying object in the presence of air resistance. Time segmentation with a very small time step is introduced, followed by updating the direction and magnitude of the air-resistance force and the gravity force. Next, an updated value for the current acceleration and velocity of the object are calculated after which the values of the new coordinates of the flying object are obtained. Continuing this process yields a very precise approximation of the actual trajectory of the object. Decreasing the size of the time segment (time slice) down to a specific critical level increases the precision of the approximation.

Time segmentation combining sampling of key parameters and corrective feedback is at the heart of the discrete-time controllers of missiles. Time segmentation is also central to the feedback control of mechatronic systems such as industrial manipulators, robots, etc. (Awrejcewicz et al., 2017).

A classification of the discussed methods for reducing risk and improving reliability based on segmentation has been presented in Figure 7. Most of the techniques are focused on reducing the likelihood of failure by a segmentation.

10. COMPARISON BETWEEN THE GENERIC PRINCIPLES APPROACH, THE DATA DRIVEN APPROACH AND THE PHYSICS OF FAILURE APPROACH FOR IMPROVING RELIABILITY AND REDUCING RISK

A common tendency in many texts devoted to reliability prediction is to choose a statistical-based, data-driven approach. Calculating the absolute reliability built in a product is often a very difficult task because often, reliability-critical data (failure frequencies, strength distribution of the flaws, failure mechanisms, repair times) are simply unavailable, particularly for new designs with no failure history. In addition, for highly reliable components and systems, the amount of existing past failures is insufficient to fit a reliable and robust statistical model because of the sparsity of failure data. This leads to increased levels of uncertainty in the model parameters and poor predictive power of the model.

Finally, past reliability data collected for a particular type of environment/duty cycle often yield poor predictions if applied to another environment/duty cycle.

The deficiencies of the data-driven approach prompted the development of the physics-of-failure-based approach to reliability improvement which is relatively independent of historical failure data. According to this approach, failures and decline in performance of components and systems occur due to underlying failure mechanisms. As a result, unlike the data-driven approach, the physics-of-failure approach addresses the underlying causes of failure. Many failure mechanisms lead to accumulation of damage which precipitates failures when the amount of accumulated damage exceeds endurance. As a result, the time to failure of components can be physically modelled. However, building accurate physics-of-failure models of the time to failure is not always possible because of the complexity of the physical mechanisms underlying the failure modes, the complex nature of the environment and the operational stresses. There is usually a great deal of uncertainty associated with the parameters of the physics-of-failure models and the quantity and size of the flaws in the components. If the goal, for example, is to increase strength, the physics of-failure modelling can help increase strength by conducting research on the link between microstructure and mechanical properties. However, this approach requires special equipment, human resources and substantial time, and a positive outcome from the research is not guaranteed. In many cases, it is much more beneficial to rely on generic methods and principles for reliability improvement and risk reduction.

Furthermore, in many failure events, several failure mechanisms are often involved, interacting in a very complex fashion. Such is, for example, the corrosion fatigue where two very complex, interdependent and synergistic failure mechanisms (‘corrosion’ and ‘fatigue’) contribute to failure. Corrosion increases the rate of fatigue damage accumulation and the progression of the fatigue crack increases the extent of corrosion. This very complex interaction and synergistic behaviour cannot be captured and modelled successfully, particularly if limited research has been done in these areas. Often, limited experimental evidence is available because of cost limitations. The experimental evidence necessary to build a correct model can be limited not only in terms of quantity but also in terms of quality. The experimental evidence usually captures the visual, easily measurable manifestations of damage, which may not necessarily reflect correctly the total existing damage responsible for the failure event. As a result, only the visual manifestation of the damage is captured and modelled as opposed to the total existing damage reaching the damage endurance limit defining failure.

Acquiring the necessary knowledge and data related to the failure mechanisms and capturing and quantifying all types of uncertainty, necessary for a correct prediction of the time to failure, is a formidable task which does not need to be addressed if the focus is placed on reliability improvement rather than reliability prediction. The generic reliability improvement and risk reduction methods do not normally rely on reliability data or on knowledge of physical mechanisms underlying possible failure modes. As a result, the generic reliability improvement and risk reduction methods are especially suited for developing new designs, with no failure history and with insufficiently researched failure mechanisms.

11. CONCLUSION

1. The paper provides analysis of the various mechanisms through which segmentation improves reliability and reduces technical risk. Segmentation can be applied with success to reduce both the likelihood of failure and consequences from failure of components and systems.
2. On the basis of theoretical arguments and examples, it has been demonstrated that segmentation increases the tolerance of components to flaws causing local damage, reduces the rate of damage accumulation and damage escalation and reduces the hazard potential.
3. On the basis of theoretical arguments, it is demonstrated that by increasing the perimeter to cross-section area ratio, segmentation reduces significantly the magnitude of the stresses in pressure vessels.
4. It is shown that segmentation improves the load distribution and reduces the magnitude of the loading stresses.
5. It is demonstrated that segmentation reduces the likelihood of failure by replacing a single critical failure on a macro level with non-critical failures on a micro-level. ThisSegmentation essentially replaces a sudden critical failure with a gradual deterioration of the system through non-critical failures.
6. It is demonstrated that segmentation can be used to reduce the likelihood of a loss from opportunity bets and the likelihood of erroneous conclusion from imperfect tests.
7. A comprehensive classification of methods and techniques for reducing risk, by using segmentation, has been proposed.

REFERENCES

Altshuller, G. S. (1984). *Creativity as an exact science: The theory of the solution of inventive problems*. New York: Gordon and Breach Science Publishing.

Altshuller, G. S. (1996). *And suddenly the inventor appeared, TRIZ, the theory of inventive problem solving (trans. from Russian L. Shulyak)*. Worcester, MA: Technical Innovation Center.

Altshuller, G. S. (2007). *The innovation algorithm, TRIZ, systematic innovation and technical creativity*. Worcester: Technical Innovation Center, Inc.

Ashby and Jones. (2002). *Materials and design: The art and science of material selection in product design*. Butterworth Heinemann.

Awrejcewicz, J., Lewandowski, D., & Olejnik, P. (2017). *Dynamics of Mechatronics Systems Modeling, Simulation, Control, Optimization and Experimental Investigations*. World Scientific.

Denardo, E. V. (2002). *The science of decision making*. John Wiley & Sons, Inc.

Epstein, R. A. (2009). *The theory of gambling and statistical logic*. Amsterdam: Elsevier.

Gadd, K. (2011). *Triz for engineers: Enabling inventive problem solving*. Wiley. doi:10.1002/9780470684320

Mämmelä, O., Hiltunen, J., Suomalainen, J., Ahola, K., Mannersalo, P., & Vehkaperä, J. (2016). Towards Micro-Segmentation in 5G Network Security. *Proc. of the EuCNC 2016 Network Management, QoS and Security workshop*.

Moore, P. (1983). *The business of risk*. Cambridge university press. doi:10.1017/CBO9780511582448

Nielsen, T. D., & Jaffray, J. Y. (2006). Dynamic decision making without expected utility: An operational approach. *European Journal of Operational Research*, *169*(1), 226–246. doi:10.1016/j.ejor.2004.05.029

Orloff, M. A. (2006). *Inventive thinking through TRIZ, A practical guide* (2nd ed.). Springer.

Orloff, M. A. (2012). *Modern TRIZ A Practical Course with EASyTRIZ Technology, A practical guide* (2nd ed.). Springer.

Paley, S. J. (2010). *The art of invention*. New York: Prometheus Books.

Rantanen, K., & Domb, E. (2008). *Simplified TRIZ* (2nd ed.). Auerbach Publications.

Richardson, J. W., & Outlaw, J. L. (2008). Ranking risky alternatives: innovations in subjective utility analysis, Risk Analysis VI, *Proceedings of the 6th international conference on computer simulation risk analysis and hazard mitigation* (pp. 213-224).

Savransky, S. D. (2000). *Introduction to TRIZ methodology of inventive problem solving*. CRC press LLC. doi:10.1201/9781420038958

Sedgewick R. (1992). *Algorithms in C++*. Addison-Wesley publishing company.

Starmer, C. (2000). Developments in non-expected utility theory: The hunt for a descriptive theory of choice under risk. *Journal of Economic Literature*, *38*(2), 332–382. doi:10.1257/jel.38.2.332

Sunstein, C. R. (2002). *Risk and reason: Safety, law, and the environment*. Cambridge University Press.

Teall, J. L., & Hasan, I. (2002). *Quantitative Methods for Finance and Investment*. Blackwell Publishing.

Terninko, J., Zusman, A., & Zlotin, B. (1998). *Systematic Innovation: An introduction to TRIZ*. CRC Press LLC.

Todinov, M. T. (2005). Limiting the probability of failure for components containing flaws. *Computational Materials Science*, *32*(2), 156–166. doi:10.1016/j.commatsci.2004.08.003

Todinov, M. T. (2007). *Risk-based reliability analysis and generic principles for risk reduction*. Elsevier.

Todinov, M. T. (2015). Reducing risk through segmentation, permutations, time and space exposure, inverse states and separation. *International Journal of Risk and Contingency Management*, *4*(3), 1–21. doi:10.4018/IJRCM.2015070101

Zhang, Y. B. (2012). The long-range monitoring system of water level based on GPRS network. In D. Zeng (Ed.), *Advances in control and communication*. Springer. doi:10.1007/978-3-642-26007-0

Michael Todorov Todinov holds a PhD related to mathematical modelling of thermal and residual stresses and a higher doctorate Doctor of Engineering (DEng) which is the engineering equivalent of Doctor of Science (DSc) in the area of new probabilistic concepts and models in Engineering. M. Todinov's name is associated with creating the foundations of risk-based reliability analysis (driven by the cost of failure) and the theory of repairable flow networks and networks with disturbed flows. A sample of M.Todinov's results includes: the discovery of closed and dominated parasitic flow loops in real networks; the proof that the Weibull distribution is an incorrect model for the distribution of breaking strength of materials and the derivation of the correct alternative of the Weibull model; a theorem regarding the exact upper bound of properties from random sampling of multiple sources; a general equation for the probability of failure of brittle components with complex shape, the formulation and proof of the necessary and sufficient conditions of the Palmgren-Miner rule and Scheil's additivity rule and deriving the correct alternative of the Johnson-Mehl-Avrami-Kolmogorov equation. M.Todinov's research has been funded by research councils, the automotive industry, the nuclear industry and the oil and gas industry.

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