The failure phenomenon: a critique

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The Failure Phenomenon
D. VALIS and L. M. BARTLETT*

*Corresponding Authors Email: L.M.Bartlett@lboro.ac.uk

Abstract: Throughout everyday life there are many events encountered where their causes, mechanisms of development and consequences are very diverse. In undertaking a safety or risk assessment it is the concept of the events’ description that is often of importance. In pure technical applications these events are related to the occurrence of failure, be it of equipment, a device, a system or an item. The theory speaks about failure itself, its mechanisms and circumstances of occurrence, but at the same time appropriate terminology is needed to describe these conditions. For observing, dealing and handling failures a probabilistic or deterministic (logic) approach can be followed. This paper considers the complex, sometimes problematic, area of the term “failure” and its related characteristics. The contribution aims to detail the total complexity of this fundamental term. A two-fold objective approach is taken. The primary objective is to address each of these complexity issues providing an understanding of the key concepts and classifications. These are related to the functions of an object and their description, classification of failures, the main characteristics of failure, the possible causes of failure, mechanisms of failure and consequences of failure. Each of these issues can be subdivided and engineering examples are used to illustrate and differentiate between such subdivisions, for example to distinguish for failure occurrence the meaning of design failures, manufacturing failures and ageing failure etc. The secondary objective is related to information sources. To gain information about a failure it may need to be found or transferred from a variety of sources, these sources have been identified and discussed. In conclusion the paper serves to form a complete picture to aid the understanding and implications of failures.

Keywords: Risk and Dependability Terminology, Failure.

1. Introduction

It is inevitable at some point failure (of equipment, a device, an item or a system) will occur. The reasons for this occurrence can vary. Usually the main factor is that the applied load exceeds the strength of the product. The load can be purely mechanical (i.e. force, tension), purely electrical (i.e. power, electromagnetic field), purely chemical (such as the effect of chemical substances), general physical (i.e. warmth, radiation), a

*Corresponding Authors Email: L.M.Bartlett@lboro.ac.uk
combination of these or of a totally different nature. Whenever the applied load exceeds the
assumed dimension of the item, unwanted (usually irreversible) processes start, and
sooner or later a failure occurs. The load can be a one time load or it can be applied a
number of times. Concerning the first instance, overload failure will occur and in the
second case either fatigue failure or wear out failure (e.g. abrasive wear or corrosion)
might occur. As time passes, the product could become weaker for any one of many
reasons (unless a failure occurs immediately). In dealing with a failure one of the basic
assumptions is that it is essential to have the device in operation before any failure is
incurred due to inner cause (e.g. operation or using an item). Idleness of an item or a
system can end in a failure due to natural ageing, but in this case the initial mechanism is
not properly understood. A relevant failure occurs mostly only during operation.

In describing failures there are many factors and characteristics to consider. One of
which is the failure profile. This profile depends on the failure causes; the failure
manifestations (namely the ways and mechanisms of failure) and the failure consequence.
These failure causes can be design failures, manufacturing failures, overstress failures,
misuse failures or degradation failures. The failure manifestations may be random,
gradual, sudden, common cause, primary, secondary, intrinsic or extrinsic. The
consequences could be insignificant, marginal, minor, major, critical, catastrophic or also
scaled differently.

Failure is a term widely used in technical practice especially concerning
dependability theory. For reliability practitioners failure is a basic term in dependability
theory, and it is key and essential for observing stochastic relations of item behavior. It
is an event which is used in probability theories on a general level, the term probability
event is used. In dependability theory it is necessary to realize the fact of failure as a
stochastic term, to understand its meaning, and to understand other links. For this reason
mathematical tools, used in dependability, are not only a dead and boring “set” of
formulas, relations and graphical expressions.

While observing a technical item, the concern is on the possible causes of failures,
their development over time, their process, mechanism, and of course their impact, effect,
or other influences which might result from a failure occurrence. It is inevitable to
realize that a failure is of key importance for operation and function of technical items.
Theory and practice in particular shows that failures occur under different situations,
various circumstances, ranging conditions, etc. Theoretically dealing with failures, it is
possible to describe their causes, nature of occurrence, process of development, and
modelling of these failures is possible at the same time. It is possible to see connections
between individual groups of failures and their profiles. A range of importance and
numerical values associated with the failures can be determined. However, the
fundamental desire is to eliminate failure occurrence, reduce its frequency, limit the
number of its occurrences over a specified time period or in relation to another observed
dependent quantity (mileage, cycles, etc.). The ultimate intention is to be able to
determine failure occurrence exactly, simply, the aim is to get a better profile of an
observed item from the view of its dependability and related properties.

Furthermore, there is a necessity to be able to describe the possible classes of failures,
their profiles, development, consequences, and other relations which might be important
for dependability theory and especially for this paper itself. The phenomena involved in
this paper are definitely not an example of a complete and synoptic list of all known and
possible events assisting a failure. The aim of this paper is to introduce the topic which
is usually believed to be obvious, familiar and clear. However, reality need not match
these ideas. The purpose of the paper is also to initiate the reader into the topic of a failure and at the same time to popularize it.

1.1. Notation

ISO 
International Organization for Standardization
IEC 
International Electrotechnical Commission
R(t) 
Reliability Function
\( t \) 
Time
PC 
Personal computer
MIL-STD 
Military Standard
MIL HDBK 
Military Handbook
RAC 
Reliability Analysis Centre
RCM 
Reliability Centred Maintenance
EPRD 
Electronic Parts Reliability Data
NPRD 
Non-electronic Parts Reliability Data
FMD 
Failure mode/mechanism distribution
SPIDR 
System and Part Integrated Data Resource
FMECA 
Failure Modes, Effects and Criticality Analysis
PHA 
Preliminary Hazard Analysis
JSA 

2. Current Terminology

Due to the ISO/IEC representatives, industrial experts and national bodies there is a set of terminology related to the issue of failure. Failure according to the present version of the IEC 60050 (191) is defined as: “termination of the ability of an item to perform a required function”. There are three things to note: (1) After failure the item has a fault; (2) Failure is an event, as distinguished from fault, which is a state; and (3) This concept as defined does not apply to items consisting of software only.

Failure according to the newly upgraded version IEC 60050 (191) is defined as: “loss of ability to perform as required”. It is noted that: (1) When the loss of ability is caused by a pre-existing condition, the failure occurs when a particular set of circumstances is encountered (see latent fault 191-44-07); (2) A failure of an item is an event, as distinct from a fault of an item (191-44-01), which is a state; and (3) Qualifiers may be used to classify failures according to the severity of consequences, such as catastrophic, critical, major, minor, marginal and insignificant, the definitions depending upon the field of application.

It results from these definitions and further analysis that the term “failure” will be understood as an event which leads straight to either a partial or complete loss of ability of an item to fulfill a required function. There is currently in process the modification and updating of terminology related to this topic, and hence the existing view of the understanding of these concepts (failure and related facts) has been changing. Just to demonstrate the complexity of the present state the following facts are introduced. According to the notes of the term failure mentioned in IEC 60050 (191)/1990, an item after failure has a fault (“An item after failure has a fault”). Owing to continual discussions about this topic it is impossible to ignore the idea that a fault does not follow a failure but precedes it. This technical incompatibility together with many others has
not been solved yet but their form has been very much discussed. A possible decision in favour of a new view will influence radically the existing approach, conception and observation of the failure.

While working with the term failure, as well as with relating states, it is necessary to take the current terminology mismatch into account and to adapt possible decisions to it. The possibility of a realized change has to be accepted along with all the resulting consequences. Unfortunately, this change will violate the understanding of all existing terms/disciplines introduced so far that deal with failure and dependability.

3. Influence of the failure

When considering a failure it is necessary to draw attention to some related events. As the term failure relates to the prevention of an items’ ability in performing a required function it is clear that this inability of a system or a product to operate in a required way is a key term determining a failure.

Based of many studies and approaches a factual scale of individual functions description was formed for a system. On the basis of these assumptions it is also essential to distinguish the influence of a failure on a function performed by an item. A failure occurrence might affect the range of the function. An outline of item functions is provided to make the understanding much easier, though it should be remembered that failure occurrence is not strictly limited to the type of item function.

A required function specifies an item task. A correct, exact and unequivocal definition is a primary starting point for all dependability definitions as well as for a right failure definition. Operation conditions affect significantly both dependability and especially possible failure occurrence, hence the reason why they have to be determined very thoroughly. The types of function are defined in Table 1. Associated with each function an engineering example is provided in the ‘Details’ column for illustration of the meaning.

The required function and/or operation conditions might be time dependent. In this case a mission profile has to be determined and all dependability viewpoints have to be related to it. A representative mission profile and corresponding dependability targets have to be stated in the item’s specification. The mission duration is often/usually considered as a parameter \( t \), that is time. The dependability function – especially the reliability function is designated as \( R(t) \). \( R(t) \) is the probability that no failure at item level will occur in the interval \( (0; t) \), often with the assumption \( R(0) = 1 \), meaning that at time \( t = 0 \) the item was in the state of operation. In order to avoid confusion a distinction between predicted and estimated (assessed) dependability should be made on the basis of a real evaluation during operation or tests. The predicted dependability is calculated on the basis of the item’s dependability structure and the failure rate. The estimated dependability is specified on the basis of a statistical evaluation of dependability tests or field data by known operating and environmental conditions.

However simple the failure definition, “it occurs when an item terminates its ability to perform its required function”, might look, it is difficult to apply it to complex items/systems. The basic operating time is generally a random variable. It is often reasonably long but on the other hand it might be very short, caused by the influence of systematic failure for example. It can also be caused by an early failure influence resulting from a transient event at turn-on.

Table 1: Function definitions
### Table 2: Failure Profile categories

<table>
<thead>
<tr>
<th>Function Type</th>
<th>Detail (and Illustrative Example)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main function</td>
<td>An intended (required) or primary function (A combustion engine is supposed to change one type of energy to another via the combustion process – the main function should be described as “energy change” in this case from chemical energy to mechanical energy)</td>
</tr>
<tr>
<td>Minor function</td>
<td>Need for providing main function. (For the combustion engine – the minor function is to ensure fuel transport/transfer into the mix chamber. So the minor function would be described as “Ensure fuel transfer/transport for the engine function”).</td>
</tr>
<tr>
<td>Supporting function</td>
<td>The aim is to provide protection of people and an environment from potential damage regarding main or minor function failure as well as common support (brakes, circuit breakers, filters, etc.). (For the combustion engine the supporting function should provide instant or consequent protection of the system/item itself, environment and/or personnel. One of the supporting functions is the regulation of the engine over spin for instant protection, covering shields of hot, rotating and exhausting parts to the operators, as secondary protection, etc. Some of the supporting functions are very closely related with the information function. Especially in the field of diagnostics and consequent system protection and regulation).</td>
</tr>
<tr>
<td>Information function</td>
<td>It provides condition monitoring, measuring, diagnostics, etc., referring to displays, indicators etc. (Given the combustion engine example the information function is supposed to provide constant, regular or other type of monitoring in order to ensure the system required state. One of these functions might be oil pressure measuring, cooling system monitoring, etc. The information from this function might be consequently used for the supporting function as countermeasures for system-engine protection from over-heating for instance. Therefore the information function might be specified as “ensure constant oil pressure monitoring”).</td>
</tr>
<tr>
<td>Interface function</td>
<td>It provides an interface between an assessed item and other items (cabling, operating elements, switches, breakers, etc.). (This kind of function serves for sharing information about the system i.e. the combustion engine with other systems (which includes the Man-Machine-Interfaces). Some interface function might be passed to the driver via the display interface e.g. oil pressure, cooling medium temperature, etc. therefore the driver may/should adjust his behavior depending on this information. Some information is passed to the driver without the option of the driver to affect it e.g. high engine revolutions are reduced while another system (ASR for instance) indicates slip of a propelled wheel. The information function might thus have following form: “to ensure constant oil pressure indication and display to the driver” or “to ensure reliable transfer of information about engine revolutions via detectors and transmitters (wires for instance)”.)</td>
</tr>
<tr>
<td>Category</td>
<td>Factors</td>
</tr>
<tr>
<td>--------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Critical stage</td>
<td><strong>Consequence seriousness</strong> (Based on the cause, mode and consequences. This includes more factors which are stated below)</td>
</tr>
<tr>
<td>Failure cause</td>
<td><strong>Misuse failure</strong> (starting the combustion engine when it is known to be outside of operational conditions e.g. too high humidity due to engine flood, too high temperature caused by over heating); <strong>mishandling failure</strong> (allowing high spin revolutions when the engine does not have the right operation temperature and is too cold); <strong>weakness failure</strong> (some part of the engine has unsatisfactory dimension and wears out or deforms very quickly); <strong>design failure</strong> (some engine parts are designed from unsatisfactory material, in unsatisfactory manufacturing procedures, etc); <strong>manufacturing failure</strong> (engine parts that fail due to incorrect manufacturing procedure for instance); <strong>ageing/wearout failure</strong> (some mechanical engine parts that wear out in a typical way and failure of electrical or plastic parts due to ageing); <strong>others</strong> (e.g. software program bug, message protocol error, etc.)</td>
</tr>
<tr>
<td>Failure mode (velocity)</td>
<td><strong>Sudden</strong> (hidden cause or instant overstress, e.g. crack of the piston rod while turning the engine into high revolution when the engine is not warmed up to operational temperature) or <strong>gradual degradation</strong> (low deterioration of mechanical parts caused by traditional wear out from contact and/or load)</td>
</tr>
<tr>
<td>Range of a consequence</td>
<td><strong>Cataleptic; complete; partial, other</strong> (this is more related to the scales and classification, for further details see section 5)</td>
</tr>
<tr>
<td>Place of occurrence</td>
<td><strong>During a test, during operation</strong> (the engine may fail while being tested for instance or while in actual operation)</td>
</tr>
<tr>
<td>Occurrence mechanism</td>
<td><strong>Primary</strong> (this type of mechanism usually occurs on the elements and does not affect the other parts of the system, e.g. piston rod crack), <strong>secondary</strong> (this type of failure mechanism is a follow on from some primary failure, e.g. piston rod crack may be the cause of an engine block rupture for instance. This mechanism depends onto another preceding failure), <strong>systematic/reproducible</strong> (this kind of failure mechanism is systematic and occurs periodically due to the possibilities of the parts being too weak, there is no new design, no new material, no alternative maintenance approach. This is also the hidden potential for failures which can be reproduced in every future project)</td>
</tr>
<tr>
<td>Verification Possibility</td>
<td><strong>Verified</strong> (this type of failure may have happened before and therefore may be verified, i.e. the combustion engine piston ring crack for instance), <strong>unverified</strong> (this type of failure may not happen again or did not happen previously therefore may not be verified)</td>
</tr>
</tbody>
</table>

A general presumption in investigating failure-free operating times is that at $t = 0$ which means that in an instant $t = 0$ the item is free of defects and systematic failures and therefore it is able to operate one hundred per cent. Besides their relative frequency, failures can be categorized in a variety of ways, namely mode, cause, consequence etc.. The basic factors of each of these main categories (critical stage, failure cause, failure mode, range of consequence, place of occurrence, occurrence mechanism, and
verification) are summarized in Table 2 along with an explanation based on the combustion engine example.

4. Failure Occurrence Cause

According to the IEC 60050 (191) the circumstances occurring during design, manufacture or use which have resulted in a failure are the cause of a failure. To decide how to prevent a failure or its reoccurrence it is necessary to know the cause of a failure. Failure causes can be classified in relation to the life cycle of the system. The cause of a failure can be intrinsic, due to weaknesses in the item and/or wearout, or extrinsic, due to errors, misuse or mishandling during the design, production and especially the use itself. Extrinsic causes often lead to systematic failures which are deterministic and might be considered like defects (dynamic defects in software quality). Defects are present at \( t=0 \), even if they cannot be discovered at \( t=0 \). Failures always seem to appear in time, even if the time to failure is very short as it can be with systematic or early failures.

These causes can be further explained in terms of [9]:
1) Design failure (e.g. resulting to/cause by design weakness/errors)
2) Manufacturing failure (e.g. resulting to/cause by design weakness/errors)
3) Ageing failure
4) Misuse failure (e.g. resulting to/cause by overstress/adverse environment impact)
5) Mishandling failure
6) Software failure

These causes are shown diagrammatically in Figure 1. Design failure occurs due to inadequate design. It is basically any failure directly related to the item design. It means that due to the item design a part of the whole degraded or got damaged and this resulted in a failure of the whole. Weakness failure occurs due to weakness (internal) inherent or induced in the system so that the system cannot stand the stress it encounters in its normal environment. Manufacturing failure is caused by nonconformity during manufacturing and processing. It is basically any failure caused by faulty processing, or inadequate manufacturing, or an error made while controlling the process during manufacturing, tests and repairs. An ageing failure is caused by the effects of usage and/or age. A misuse failure is caused by misuse of the system (operating in environments for which it was not designed). A mishandling failure is a failure caused by incorrect handling and/or lack of care and maintenance. Software error failure is caused by a PC programmer error.

The failure mechanism is a very complex and extensive passage of the failure profile. It can be sudden or gradual with its relating manifestations. The failure mechanism maybe physical, chemical, electrical, thermal or other process that results in failure mode. The mode (manifestation, course) of a failure is a symptom (local effect) by which a failure is observed. For example – opens, shorts, or drifts (for electronic components). Brittle rupture, creep, cracking, seizure, or fatigue (for mechanical components), etc.
The general relations of failure modes are shown in the Figure 2. The connections related to these aspects of a failure are shown Table 3. Considering the combustion engine example the intermittent failure might occur when the operation condition/state of the engine is not as required. For instance a piston rod crack may occur when the engine is not warmed up to the operation temperature (or even the environment temperature is below zero degrees of Celsius) and it performs a high number of revolutions. An extended failure is consequently represented by a partial fault or degradation of the 100% service state. For example if one spark plug fails (assuming the engine has more than one cylinder, e.g. 4 and can work whilst one is not functioning). A sudden failure is one where this is no previous indication of this kind of failure. For the spark ignition engine an example would be one spark plug fails. A gradual failure may happen whilst observing longer lasting symptoms of service capability degradation. For the combustion engine for instance, it may be that a higher fuel consumption is observed, or using diagnostic equipment e.g. a higher oil particle concentration is recorded which may lead to failure of the part which they are related to.
Table 3: Failure Mechanism Breakdown

<table>
<thead>
<tr>
<th>Failure Mode</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intermittent (incoherent) failure</td>
<td>A failure which lasts only for a short time. A good example of this is a fault that occurs only under certain conditions occurring intermittently (irregularly).</td>
</tr>
<tr>
<td>Extended failure</td>
<td>Failures that occur until some corrective action rectifies the failure. They can be divided into two categories: sudden or gradual.</td>
</tr>
<tr>
<td>Sudden failure</td>
<td>A failure which occurs without warning</td>
</tr>
<tr>
<td>Gradual failure</td>
<td>A failure which occurs with signals to warn of the occurrence. Usually it is a case of significant behavior changes (decreasing performance, increasing temperature, rising vibrations, etc.).</td>
</tr>
</tbody>
</table>

There is a need to distinguish among different failure mechanisms of mechanical, electrical and hydraulic parts. The differentiation is so complex that it can not be easily presented in this paper.

5. Failure Consequences

Many information sources use the term failure consequence. Also many standards define them and work with them differently. This section aims to help to clarify the concept of failure consequences from a reliability perspective. The effect (consequence) of a failure can be different if considered on the item itself or at a higher level. A usual classification of a failure has the following qualitative profile and is: non-relevant, partial, complete, ..., critical. Since a failure can also cause further failures in an item or a system, a distinction between primary and secondary failure is important.

Table 4: Severity of a failure mode

<table>
<thead>
<tr>
<th>Severity level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catastrophic failure</td>
<td>A failure that can lead to death or can cause total system (item) loss. (For a vehicle for instance, the total failure of the brake system may lead both to single/multiple death and/or may cause total system loss).</td>
</tr>
<tr>
<td>Critical failure</td>
<td>A failure which results in many serious injuries or major system damage. Sometimes we think of it as a failure, or combination of failures, that prevents an item from performing a required mission. (Using a vehicle example partial loss of the brake system may lead both to serious injuries or/and major system damage).</td>
</tr>
<tr>
<td>Marginal failure</td>
<td>A failure that leads to minor injury or minor system damage. (While changing a wheel on a vehicle due to tyre defect the failure of the car jack resulting in collapse of car may lead to minor injury for instance and/or minor damage of the system).</td>
</tr>
<tr>
<td>Negligible failure</td>
<td>A failure that leads to less than minor injury of system damage. (Failure of a vehicle light bulb in the dashboard can hypothetically lead to minor injury and/or minor damage of the system).</td>
</tr>
</tbody>
</table>
The severity of a failure mode is classified into four main categories. In accordance with the MIL-STD 882 Table 4 lists these, with examples:

Another classification can be found in the RCM approach where the following classes are used:

- **Failures with safety consequences** (e.g. tyre failure of a car may consequently lead to serious safety related consequences);
- **Failures with environmental consequences** (e.g. fuel tank rupture or gear/engine box rupture of a car may consequently lead to serious environmental consequences);
- **Failures with operational consequences** (e.g. the impossibility of opening the front doors/failure of the door lock of a car before the start of the voyage may consequently lead to operational consequences);
- **Failures with non-operational consequences** (a failure of one light bulb in the front light does not necessarily need to lead both to safety, environmental or operational consequences).

A classification of the failure severity into groups (categories) is given in more standards. Each of them is specific in a way and corresponds with a presupposed application. The IEC 61882, IEC 60812, IEC 50 126 and many others are some of the examples. It is not the ambition here to make a complete list of failure consequences and their classification.

### 6. Sources of Failure Profile Information

There are various sources available from which failure measures and their characteristics can be obtained. The main sources are:

1) Data on elements’ reliability guaranteed by a producer.

2) Conclusive test results (observation) of the same (comparable) item reliability. It is based on the standardized assessment of reliability tests of technical items. The methods and methodologies of how to conduct tests are standardized for different equipment.

3) Predictions – standardised calculation of item’s reliability based on a reliable source (MIL HDBK 217F). This is the American military standard that enables the data on electronic elements’ reliability to be estimated. It is commonly used when estimating the elements’ failure rate especially in military applications.

4) Specialized information databases on elements’ reliability (specialized in terms of elements’ profile or conditions of usage). Specialized information databases on elements’ reliability are usually established and kept to meet the needs of single industrial branches or technical areas. The data acquired when observing items in operation or the results of specialized dependability tests are collected in the databases. One of the most respectable and frequently used databases on reliability in this area is the database established and kept by the Reliability analysis centre (RAC) which at present distributes three important databases on the commercial basis: EPRD-97; NPRD-95; FMD-97; SPIDR 2007.
5) General information database on elements’ reliability. These databases are usually
published as parts of specialized literature in the dependability area. The information
put in them is usually very general.

6) Expert estimations. Expert estimations of numerical values of reliability measures
might be used only when appropriate values cannot be specified by a different, more
reliable method. The authors of the article know from experience that this solution is
accepted only as an exception because in most cases the numerical values of reliability
measures can be determined by other methods described in this paper.

7. Example of engineering item

Below, there are presented selected basic items (elements) and their failure mechanisms
(mode/propagation), some causes and characteristic percentage distribution of such
modes. All information examples are taken from [5], [6], [7] and [8]. As seen from the
example, some failure mechanisms are caused by incorrect manufacturing, some by
misuse and some of them by wear out for example.

Electronic part: Failure mode
Capacitor: Drift (approx 32%)
  Shorted (approx 20%)
  Worn (approx 15%)
  Broken (approx 14%)
  Change in capacitance (approx 13%)
  Intermittent operation (approx 3%)
  Opened (approx 3%)

Mechanical parts: Failure mode
  Statically loaded:
    o Demountable:
      ▪ Screw: Loose (approx 50%)
      ▪ Worn (approx 25%)
      ▪ Induced – vibration/missing (approx 25%)
    o Non-rewirable:
      ▪ Welded joint: Broken (approx 50%)
      ▪ Workmanship (approx 50%)

  Dynamically loaded:
    ▪ Bearing: Worn (approx 60%)
      Binding/Sticking (approx 20%)
      Loss of lubrication (approx 10%)
      Contaminated (approx 5%)
      Scored (approx 5%)

Hydraulic parts: Failure mode
  ▪ Seal: Cut/Scarred/Punctured (approx 52%)
    Aged/Deteriorated (approx 30%)
    Leaking (approx 7%)
8. Conclusion

This contribution gives a general overview in the area of the supposed basic term “a failure”. It can be seen from the knowledge expressed that there are many facets to consider when dealing with this term. As the understanding of all related matters is very complex it is not possible to express an exhaustive compendium of knowledge and experience, however the key issues are explained. It is possible that some reliability and safety engineers might be confused when beginning with a specific analysis (e.g. FMECA, PHA, JSA, OSHA, etc.). The main benefit of this contribution is to be a general and introductive material for understanding a failure, its full profile with all related characteristics. The paper provides the information to orient the analyst on the appropriate information source which is necessary for the analysis. There is not the possibility to contribute all the overwhelming material but the most important outcome of the paper is the fundamental guideline from a broad perspective of this term for basic orientation in the reliability and safety engineering matters.

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References