Chapter 3
Failures and Failure Classification

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Slides related to the book

System Reliability Theory Models, Statistical Methods, and Applications
Wiley, 2004

Homepage of the book: http://www.ntnu.edu/ross/books/srt
Learning objectives

▶ To learn the key terms and concepts related to hardware failures

▶ To become familiar with some approaches to failure classification
**Failure - 1**

**Failure:** The termination of the ability of an item to perform a required function.

A failure is always related to a **required function**. The function is often specified together with a **performance requirement**.\(^1\)

A failure occurs when the function cannot be performed or has a performance that falls outside the performance requirement.

**Shutdown valve**

According to the performance requirement, the maximum closing time of a shutdown valve shall be no longer than 15 seconds. A failure of the closing function occurs when the closing time exceeds 15 seconds.

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\(^1\)Also called a functional requirement
A failure is an event that occurs at a specific point in time.

It is not always possible to observe when the failure occurs. This may especially be the case when:

- The function is slowly deteriorating
- The function is dormant (e.g., safety systems)

The failure may sometimes be:

- Manifested a certain time after the failure occurred (i.e., when the function is demanded)
- Revealed and corrected before it is manifested (i.e., when the function is tested)
**Fault**: The state of an item characterized by inability to perform a required function

Whereas a failure is an event that occurs at a specific point in time, a fault is a state that will last for a shorter or longer period.

In most cases, an item will have a fault after a hardware failure has occurred – and we say that the item is in a failed state.

Design and installation errors may also prevent the item from performing its required function. The item has a fault that is not preceded by any hardware failure and we call this fault a systematic fault.
Error: A discrepancy between a computed, observed or measured value or condition and the true, specified or theoretically correct value or condition

[IEC 60050-191]
To identify all potential failure modes of an item, we need to identify all the functions of the item, and the associated performance requirements.

Even “simple” items may have a high number of functions that are difficult to identify.

Try, for example, to identify all the functions of a mobile phone.
Function categories

It may sometimes be useful to have a list of general function categories (examples for a water pump):

- Essential functions (e.g., pump water)
- Auxiliary functions (e.g., contain water - prevent leakage out)
- Protective functions (e.g., prevent sparks from electro-motor)
- Information functions (e.g., measure internal pressure, temperature)
- Interface functions (e.g., connect to in/out pipes)
- Superfluous functions (e.g., functions remaining after the system has been modified)
Failure mode - 1

**Failure mode:** The way a failure is observed on a failed item. [IEC 191-05-22]

A failure mode is the way in which an item could fail to perform its required function. An item can fail in many different ways – a failure mode is a description of a possible state of the item after it has failed.

**Pump**

Performance requirement: The pump must provide an output between 100 and 110 liters per minute.

Associated failure modes may be:

- No output
- Too low output
- Too high output
- Too much fluctuation in output
A failure mode is always related to a required function and the associated performance requirement.

A failure mode is description of a fault (i.e., a state) and not of a failure (i.e., an event). A more correct term would therefore be fault mode. Some data sources list, for example, corrosion as a failure mode. This is wrong. Corrosion is a failure mechanism and may be a cause of a failure mode. It is, however, not a description of a lost function.

\(^2\)This term is used in IEC 60300, but failure mode is so common that a change of the term might confuse the users.
General failure modes

1. Failure during operation
2. Failure to operate at a prescribed time
3. Failure to cease operation at a prescribed time
4. Premature (spurious) operation

[BS 5760-5]
Failure modes of a water tap

- Fail to open (on demand)
- Fail to close (on demand)
- Cannot fully open
- Fail to regulate flow
- Leakage through (dripping)
- Leakage out (from tap seals)
- Fail to regulate temperature
- Etc.
Failures may be classified according to:

- **Failure causes**
  - Primary failure (inherent weakness failure)
  - Secondary failure (overstress or misuse failure)
  - Command fault

- **Time of failure**
  - Sudden failure
  - Gradual failure

- **Detectability**
  - Evident failure
  - Hidden failure

- **Degree of failure**
  - Partial failure
  - Complete failure
Failure classification - 2

Failure

- Intermittent failure
  - Complete failure
    - Sudden failure
      - Catastrophic failure
    - Gradual failure
  - Gradual failure
- Extended failure
  - Partial failure
    - Sudden failure
    - Gradual failure
  - Degraded failure
Failure cause - 1

Failure cause: The circumstances during design, manufacture, or use which have led to a failure.

Wikipedia gives the following definition:

“Failure causes are defects in design, process, quality, or part application, which are the underlying cause of a failure or which initiate a process which leads to failure. Where failure depends on the user of the product or process, then human error must be considered.”
NUREG/CR-5460 applies the following terms when describing the failure causes:

- **Proximate cause**: A condition that is readily identifiable as leading to the failure.
- **Conditioning event**: An event that predisposes a component to failure, or increases its susceptibility to failure.
- **Trigger event**: An event, usually external to the component, that activates the failure, or causes the transition to the failed state.
- **Root cause**: The most basic reasons why the component failed, that - if corrected- would prevent recurrence.
Failure mechanism

Failure mechanism: The physical, chemical or other process which has led to a failure.

Examples include:

- Corrosion
- Erosion
- Fatigue
- Fretting
- and so on
Failure cause classification

- Failure cause
  - Design
    - Design failure
  - Manufacturing
    - Manufacturing failure
  - Use
    - Misuse failure
    - Misuse failure
    - Ageing failure
OREDA failure classification

The OREDA project classifies failures according to their extensiveness.

- **Critical failure**
  - Sudden failure that causes termination of one or more fundamental functions

- **Degraded failure**
  - Gradual or partial failure. In time, such a failure may develop into a critical failure

- **Incipient failure**
  - An imperfection in the state or condition of an item so that a degraded or critical failure can be expected to result if corrective action is not taken