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Clarification of Failure Terminology by Examining a Generic Failure Development Process

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Abstract: *One key objective of good plant asset management is to prevent undesirable failure that may cause loss of life, destruction of asset, loss of economic benefit or damage to the environment. In order to deploy strategies that prevent failure, one needs to first understand the processes leading to failure, and definitions used for describing the failure of physical assets. A number of different definitions for the same terms related to equipment failure can be found in the literature. The looseness of terminology and often overlapping shades of meaning lead to ambiguity and confusion. This paper aims to offer clearer definitions derived from examining a generic failure development process exhibited by physical assets (herein referred to as "equipment").*
Keywords: *Failure terminology, failure mechanism, failure effect, failure symptoms, failure warnings, health indicators*

1. Introduction

Plant Assets are defined as the fixtures, implements, machinery and apparatus that have the purpose of providing an economic and/or social benefit. Failure (of plant assets) is generally understood as the termination of the ability of equipment to perform to its designed capacity. Terms related to failure like failure mode, failure causes, failure effects and failure symptoms, are given different definitions in the plant asset management world. Some definitions of terms found in literature are given in appendix A.

These terms are often used in various ways, leading to confusion and ambiguity in the asset management community. One possible reason for this confusion is that these terms are used in different contexts and times within the failure development process.

2. Background to Risk Management Methodologies

To provide clearer definitions of terms, it is useful to look generically at how an equipment failure develops over a time period. A model for failure terminology within this context is presented in this paper.

2.1. Failure Event

The cause and effect approach is found to be useful. For every effect, there is always at least two causes: at least one action and at least one condition [2]. Conditions change over time and the actions are momentary. For example, to start a fire, the conditions needed are heat, fuel and oxygen. The momentary action required is the action of ignition (such as striking a match).

In the cause and effect chain, the effect is a ***failure event*** if the termination of the ability of the equipment to perform its designed capacity occurs at that instant.

In terms of equipment failure, deteriorated physical condition(s) and the action of starting up equipment under these conditions may result in equipment failure. Another example is where the equipment may be in good condition but it is operated beyond its design capacity (e.g. overstress). In other words, a failure event is the result of:

- deteriorated equipment conditions and a triggering action, or
- good equipment conditions and inappropriate triggering actions

2.2. Failure Symptoms

Failure symptoms are indicators or signs of a failure event. These indicators or signs may manifest before the event occurs (as a "***failure warning***"), or after the event occurs (as a "***failure effect***").

2.2.1. Before a failure event

A *failure event* is the result of a chain of cause and effect relationships. As discussed above, a *failure event* can be the result of either:

- deteriorated equipment conditions and a triggering action, or
- good equipment conditions and inappropriate triggering actions

The deteriorating conditions are often observable via human senses or detectable via instrumentation. The equipment may send out signals or symptoms that it is not 'feeling too well' prior to actual failure. These

'symptoms' may be referred to as *failure warnings*, and are opportunities for detecting changes and/or abnormality in equipment operations.

A new and generic term introduced here is "***Health Indicator***". *Health Indicators* are measurable parameters of equipment condition or performance that identify the difference between normal (or healthy) condition and abnormal condition.

Failure Development Period is the time from first signs of deteriorating health condition being able to be detected to the actual time of a *failure event*. The length of the time period depends upon many factors such as the durability of the equipment, its duty cycle, the operating environment (load, weather conditions), and so on. The *failure development period* is the time where appropriate intervention may prevent a failure from occurring.

2.2.2. After a failure event

After a *failure event*, a term loosely used to describe the impact or influence the failure has on the equipment is *"failure effect"*. Unfortunately, the term *"failure effect"* has been used in the literature in diverse ways. In this paper, we suggest the following delineation of terminology that more precisely defines the aspects of failure after a *failure event* has occurred.

Failure Effect. *Failure effect* is the immediate outcome that a failure event had upon the operation, function or status of the equipment. This *failure effect* is something that would be observable by a human operator, or detectable by instrumentation. This Information indicates that the equipment is not functioning as expected, or according to its specifications.

Failure Mechanism. This term describes "how" the equipment failed – and specifically refers to the physical, chemical or other process or *mechanism* that produced the failure event.

Note: The term *"failure mode"* has also been used in texts to describe this phenomenon, but has also assumed other definitions in different contexts.

Failure Cause. *Failure causes* are the reasons "why" a failure event occurred. *Failure causes* may be quite obscure and not immediately apparent, and may require significant investigation, or *root cause analysis* for the underlying reasons to be revealed.

Failure Consequences. This term is sometimes used interchangeably with *failure effect*. In this lexicon, *Failure Consequences* refer to the impact that a *failure event* has upon its operational context, including business, people, and the environment. *Failure consequence* is an established term in the discipline of risk management, and is described by such measures as financial losses, human injury or other undesired outcomes.

In essence, *failure effect* refers to the impact of a failure to the equipment function, whereas *failure consequence* refers to the impact upon the external world.

Failure Criticality. This term describes the magnitude of the *failure consequence,* and is synonymous with the terms "impact" or "severity" used in risk management.

Note: There are generally two interpretations of *Failure Criticality*. In FMECA (Failure Mode, Effects and Criticality Analysis), "Criticality" is synonymous with the "risk" of a failure as compared to the risks of all other quipment *failure modes* (*failure mechanisms*). Another school defines failure criticality as a ranking or severity of failure consequence. To avoid such confusion, this paper proposes that the term *Failure Criticality* not be used at all. If a ranking or severity of *failure consequence* is required, then the proposed term is "***Consequence Ranking***". This term applies to the concept of ranking the magnitude of consequences, as differentiated from the notion of "***Risk Ranking***" (where risk is the combination of consequence and likelihood).

2.2.3. Failure development process model

The failure development process model is illustrated in Figure 1.

- The blue boxes refer to the physical equipment and a possible *failure event*.
- The green boxes refer to processes of investigation after a *failure event*.
- The pink boxes refer to the application of a strategy to mitigate a future *failure event*.

Before a *failure event*, symptoms of failure may be observable or measureable as *failure warnings* as conditions deteriorate, or as the equipment is subject to adverse treatment.

After the *failure event*, the symptoms are observable or recognizable as *failure effects. Failure effects* may be classified and recorded over time to provide a history of equipment behaviour and a source of information for historical and/or statistical analysis.

A good investigation of the failure will take into account both *failure warnings* and *failure effects* and attempt to ascertain:

- how the failure occurred – the *failure mechanisms*
- why the failure occurred – the *failure causes*

Given the results of the investigation, a strategy may then be developed to protect against future failure. The strategy will consist of the following generic features:

Preventive Actions – tasks designed to maintain the condition of equipment and its environment within desired specifications, and to prevent abnormal usage or abuse.

Proactive Actions – the installation and monitoring of measures that are capable of detecting the *failure warnings. Health Indicators* are the instruments of strategy selected to monitor and act upon the available warnings of failure.

An Example of the application of this terminology is provided in Table 1.

3. Conclusion

A number of different definitions for the same terms related to equipment failure are found in literature. The looseness of terminology leads to ambiguity and confusion. This paper offers a reconciled list of definitions

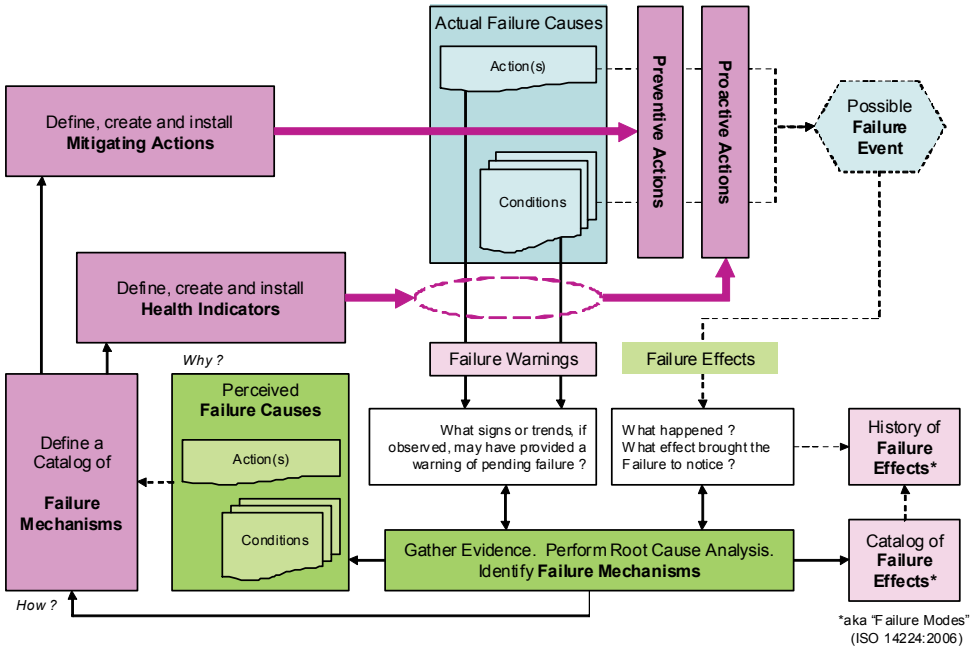

Fig. 1. A Model for the Failure Development Process

	Before Failure Event	After Failure Event				
	What? (signs)	What? (effect)	How?	Why?	What is the impact to?	How severe is the failure compared to others?
Preferred terminology for physical asset	*Failure warning*	*Failure Effect*	*Failure Mechanism*	*Failure Cause*	*Failure Consequence*	*Consequence Ranking or Risk Ranking*
Example: Centrifugal pump	Flow reduced	Failure to start on demand. Not pumping	Shaft failure. Switch failure. Electrical failure Cavitation.	Switch damage. Burnt cables due to overheating. Misaligned shaft	Stop production for 1 day.	It is ranked 20 out of 30.(1 being the most severe)

Table 1. The "What, How and Why" related to Equipment Failure

Terms	Definitions (Equipment context)
Failure	The termination of the ability of the equipment to perform a required function.
Failure Event	An occurrence of the termination of the ability of the equipment to perform a required function.
Failure Warning	Detectable signs of deteriorating conditions and/or adverse actions that provide warning of a potential failure.
Failure Effect	The immediate outcome that a failure event has on the operation, function or status of the equipment.
Failure Mechanism	The physical, chemical, electrical, thermal or other process or mechanism that produces failure event.
Failure Cause	The deteriorated condition of the equipment, or the adverse action that has led to a failure.
Root Cause	Any cause in the cause-effect continuum that is acted upon by a solution such that the failure event does not recur.
Failure Consequence	The impact that a failure event has upon the failed equipment's operational context, including business, people, and the environment.
Failure Development Period	Failure Development Period is the time from first signs of deteriorating health condition being able to be detected to the actual time of a failure event. The length of the time period depends upon many factors such as the durability of the equipment, its duty cycle, the operating environment (load, weather conditions), and so on.
Health Indicator	A measure that differentiates between normal (expected) and abnormal condition and/or performance. Health Indicators are instruments of strategy chosen to monitor and act upon available warnings of failure.

Table 2. Proposed Definitions for Equipment Failure

Terms	Definition	Reference
Fault	The inability of an entity to perform its required function, resulting in unavailability.	Smith (1993)
Failure	Termination of the ability of an item to perform a required function	ISO 14224 (1999)
	A loss of function or a malfunction of a system/part thereof.	Moubray (1997)
	Inability to perform within specified limits of an intended function.	Hessburg (2001)
	Performance outside the upper and lower specified acceptable levels.	Tweeddale (2003)
	A cessation of function that has consequences (usually meaning death, injury or damage) beyond a component or entity merely becoming unavailable to perform its function.	Smith (1993)
Functional Failure	Inability of any asset to fulfil a function to a standard of performance which is acceptable to the user.	Moubrary (1997)
Failure Mechanism	The physical, chemical, electrical, thermal or other process which results in a Failure	MIL-STD-721C 12 June 1981
	The failure mechanism is the physical, chemical or other process or combination of processes that leads to the failure. It is an attribute of the failure event that can be deduced technically, e.g. the apparent, observed cause of the failure.	ISO 14224 (2006)
Failure Mode	Effect by which a failure is observed on the failed item	ISO 14224 (1999)
	A single event that causses a functional failure	Moubray (1997)
Failure Effect	A description of what happens when a failure mode occurs	Moubray (1997)
	Expected influence on the components and subsequent plant behaviour	Grimmelius et al. (1995)
Failure Cause	Circumstances during design, manufacture or use which have led to a failure	ISO 14224 (1999)
Root Cause	Any cause in the cause-effect continuum that is acted upon by a solution such that the failure event does not recur.	Gano (1999)
Failure Symptom	Expected measureable variables (Temperature, pressure, electrical power)	Grimmelius et al. (1995)
	An identifiable physical condition by which a potential failure can be recognized	MIL-STD-2173(AS) 21 Jan 1986
Failure Consequence	The way (or ways) in which a failure mode or a multiple failure matters	Moubray (1997)

Appendix A

by examining the equipment failure development process. The proposed definitions for equipment failure to be used are listed in Table 2.

4. References

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