Equipment Reliability

FPST 4333

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What is Reliability?

The ability of an item to perform a required function under stated conditions for a stated period of time.

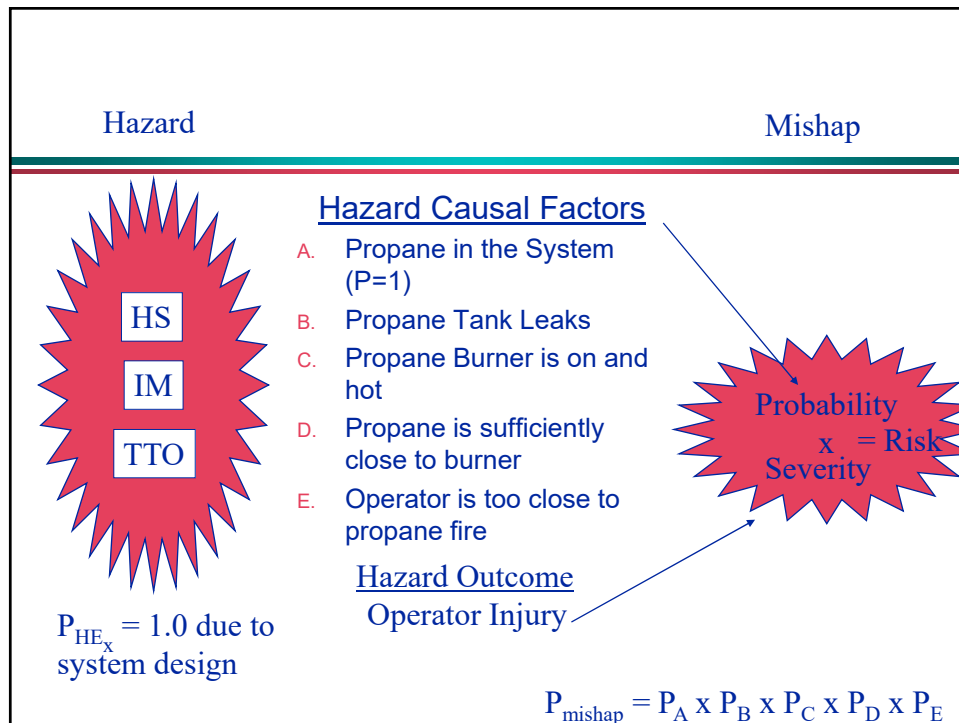*British Standard BS4775 Part 1 (1987)*

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Lusser's
Product Law of Reliabilities

the probability of success ρ in a system in which all the components must work if the system is to work is the product of the individual probabilities of success ρ_i

$$\rho = \prod_{i-1}^{n} \rho_i$$

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Hazard   Mishap

Hazard Causal Factors

HS

IM

TTO

A. Propane in the System (P=1)

B. Propane Tank Leaks

C. Propane Burner is on and hot

D. Propane is sufficiently close to burner

E. Operator is too close to propane fire

Probability
x = Risk
Severity

Hazard Outcome
Operator Injury

$P_{HE_x} = 1.0$ due to system design

$P_{mishap} = P_A \times P_B \times P_C \times P_D \times P_E$

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Reliability vs. Quality Control

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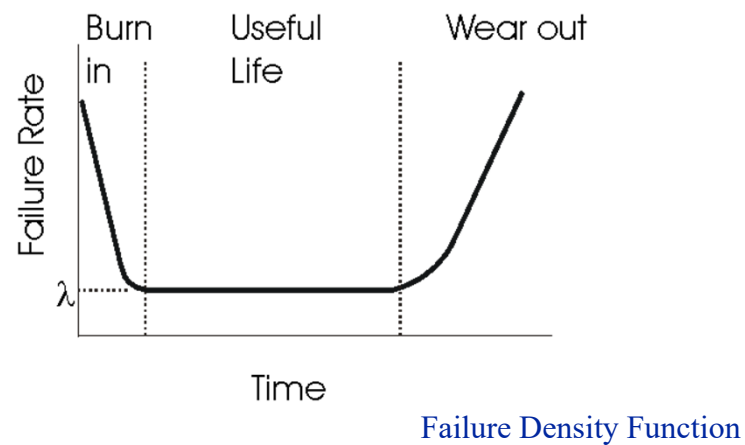# Reliability

It is a probability

It is a function of time

It is a function of defined conditions

It is a function of the definitions of failure

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Constant Over the Lifetime?

Only in Region 2 of bathtub curve, i.e. "useful life"

Failure Density Function

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Types of Failure

Failure in Operation

Failure to Operate on demand

Operation before demand

Operation after demand to cease

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Definitions

Mean Life
⇨first moment of the failure density function

Mean Time Between Failure (MTBF)
⇨<u>Total operating time</u> of the items divided by the <u>total number of failures</u>

⇨applied to a population of components, equipment, or systems in which there is repair.

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Sources and Types of Failure Data

Plant Specific Data
⇨equipment failure experience at a plant

Generic Data
⇨Aggregated across plants and industries

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Where does Generic Failure Rate Data come from?

Process Equipment Reliability Data (PERD) AIChE/CCPS, 1989

Offshore and Onshore Reliability Data (OREDA)

Reliability Analysis Center

https://www.ntnu.edu/ross/info/data

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Failure Rate Data for Various Selected Process Components

Instrument	Failures/Year
Controller	0.29
Control valve	0.60
Flow measurement (fluids)	1.14
Flow measurement (solids)	3.75
Flow switch	1.12
Gas–liquid chromatograph	30.6
Hand valve	0.13
Indicator lamp	0.044
Level measurement (liquids)	1.70
Level measurement (solids)	6.86
Oxygen analyzer	5.65
pH meter	5.88
Pressure measurement	1.41
Pressure relief valve	0.022
Pressure switch	0.14
Solenoid valve	0.42
Stepper motor	0.044
Strip chart recorder	0.22
Thermocouple temperature measurement	0.52
Thermometer temperature measurement	0.027
Valve positioner	0.44

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Failure Rate Data

Time Related

⇨ Failures per 10^6 hours

⇨ failures per year

Demand Related

⇨ Failures per 10^3 demands

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When to Use Demand Failure Probabilities versus Failure Rates?

Example: Do hoses fail after a certain number of liquid transfers or after a certain number of years?

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Anatomy of Failure

Initiating (root) cause

Contributory causes

Failure Modes

⇒ Failure to operate

⇒ No output

⇒ Failure to alarm on demand

Failure Effect

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Types of Failure

Active

⇒ Physical motion or activity

⇒ Rotating equipment, valve actuation

Passive

⇒ No physical actuation

⇒ Piping, storage vessel

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Failure Modes

Catastrophic:

⇨ Sudden and causes termination of one or more functions

Degraded

⇨ Gradual or partial

Incipient

⇨ Imperfection in condition of equipment

⇨ Results in degradation or catastrophic failure

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Active Equipment Failure Modes				
Failure Severity				
		Catastrophic	**Degraded**	**Incipient**

Change in item or equipment condition	**Change in Operation**	1. Failure to operate
		2. No output
			1. Low Output
			2. High Output
			3. Erratic Output
			4. Locked in One mode of Operation
			5. Output outside operating envelope
				Discovered through:
				1. Local inspection
				  • Overheating, leaks, contamination, noise, severe vibration, odor, cracks, etc.
				2. Testing
				  • Outside operating envelope while in standby mode
				3. Monitoring
				  • Trend towards failure

	Change without demand (Change of State)	A spurious (false): 1. Start/Stop 2. Insertion 3. Withdrawal 4. Actuation 5. Response 6. Opening 7. Closing	1. Premature or delayed actuation 2. Wont stay open or closed	Discovered through: 1. Testing • Failure or diminished ability to transmit or retain energy during standby mode 2. Local Inspection
	Change of State	Failure to: 1. Start 2. Stop 3. Insert 4. Withdraw 5. Actuate 6. Respond to Command 7. Open 8. Close	Improper Response: 1. Partially open, close, etc. 2. Oscillation (failure to assume a fixed position)	

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Passive Equipment Failure Modes				
	Catastrophic	**Degraded**		**Incipient**
Change in item or equipment condition	**Failure to retain or transmit energy** 1. Breech of pressure or static fluid boundary 2. Major leaks 3. External leaks 4. Internal Leaks 5. Implosions 6. Loss of energy transport or exchange capability 7. Blocked or stopped flow 8. Loss of heat transfer capability 9. Major heat loss (loss of insulation) 10. Loss of structural integrity 11. Failure to support or brace 12. Fracture of all members 13. Physical distortion 14. Distortion under load 15. Failure to fasten or join 16. Removable fastener failure 17. Failure of permanent joint 18. Weld Failure 19. Imbed Failure	**Diminished ability to retain or transmit energy** 1. Degradation of pressure or static fluid boundary 2. Minor leaks 3. External Leaks 4. Internal Leaks 5. Interference with energy transport or exchange capability 6. Restricted Flow 7. Reduced heat transfer capability 8. Minor heat Loss 9. Structural integrity compromised 10. Reduced support capability 11. Fracture of par of structural members 12. Minor physical Distortion 13. Partial Failure to fasten or join	**Change in Operation**	1. **Testing:** Failure or diminished ability to transmit or retain energy during the energized mode of operation 2. **Local inspection** (leaks, vibration, odor, cracks, etc. 3. **Monitoring:** Monitoring trends towards failure, during the energized mode of operation
			Change of State	1. **Testing:** Failure or diminished ability to transmit or retain energy during the energized mode of operation 2. **Local Inspection**

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Failure Rate Taxonomy

tax·on·o·my
/takˈsänəmē/

noun
BIOLOGY
1. the branch of science concerned with classification, especially of organisms; systematics.
     •the classification of something, especially organisms.
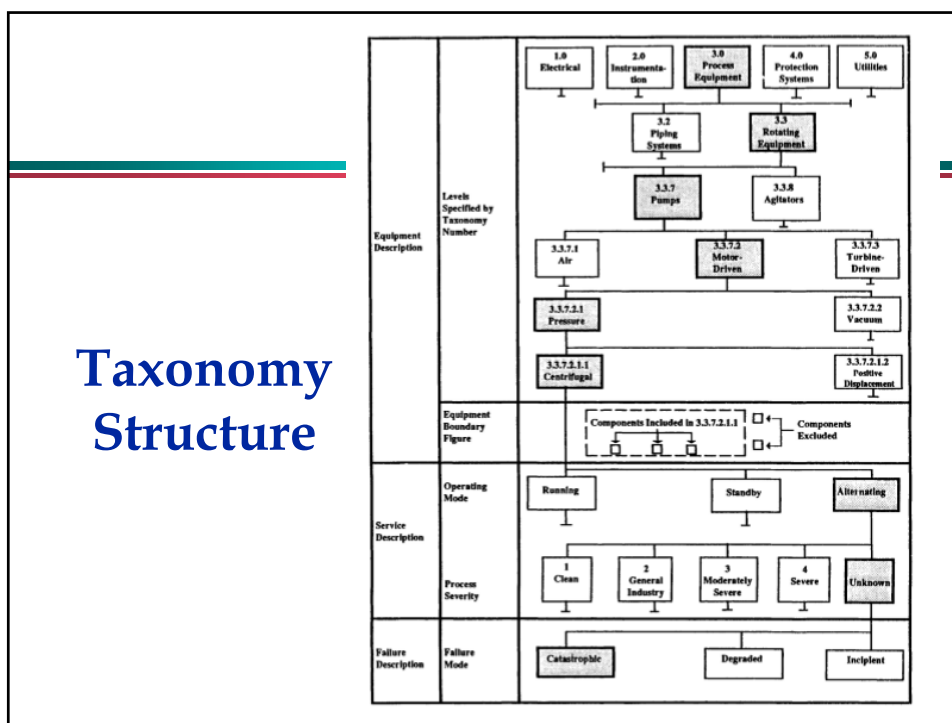"the taxonomy of these fossils"
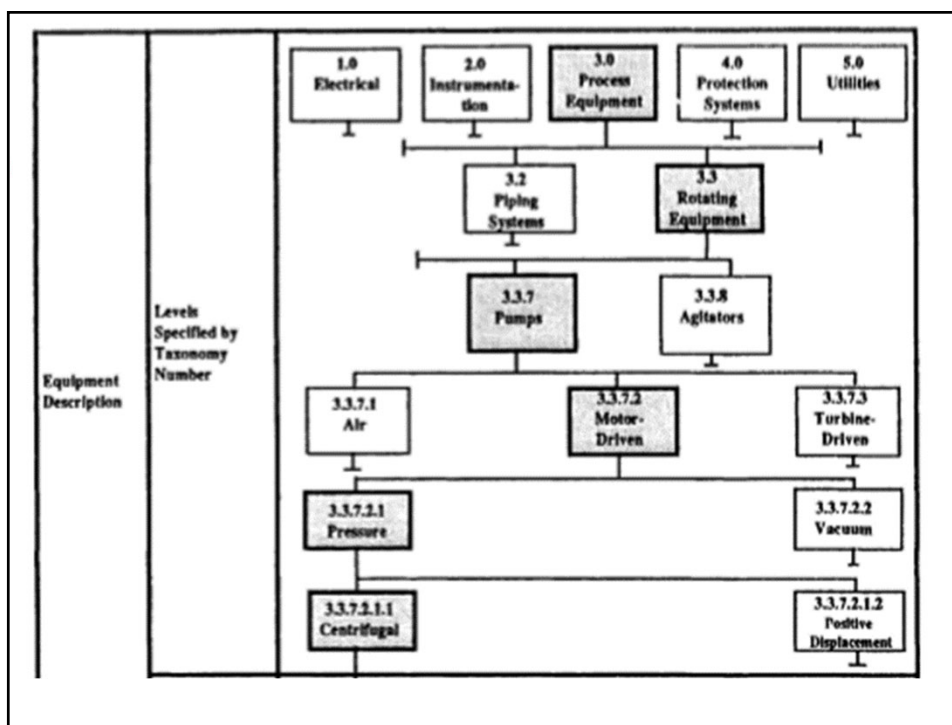   •a scheme of classification.
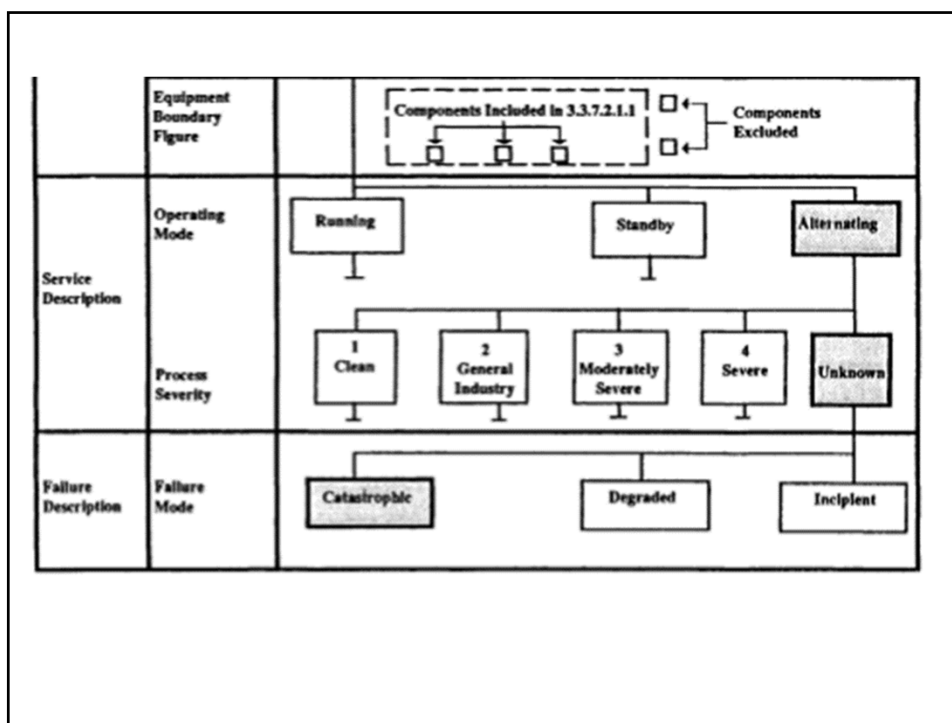plural noun: **taxonomies**
"a **taxonomy of** smells"

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Taxonomy Structure

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CCPS Generic Data Sheet

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Equipment Boundary

POWER SUPPLY   PROCESS IN

MOTOR — TRANSMISSION — PUMP — PROCESS OUT

INCLUDED:
SEAL SYSTEM
CONTROL UNIT
BASEPLATE

— — — BOUNDARY

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DATA ON SELECTED PROCESS SYSTEMS AND EQUIPMENT

Taxonomy No.	3.3.7.2.1.1			Equipment Description	ROTATING EQUIPMENT- PUMPS MOTOR DRIVEN-PRESSURE-CENTRIFUGAL	
Operating Mode	ALTERNATING			Process Severity	UNKNOWN	

Population	Samples	Aggregated time in service (10^6 hrs)		No. of Demands		
		Calendar time	Operating time			

Failure mode	Failures (per 10^6 hrs)			Failures (per 10^7 demands)		
	Lower	Mean	Upper	Lower	Mean	Upper
CATASTROPHIC						
a. Fails while Running	43.3	292.0	862.0			
b. Rupture						
c. Spurious Start						
d. Fails to Start on Demand				0.360	10.80	43.0
e. Fails to Stop on Demand						
DEGRADED						
a. Fails to Run at Rated Speed	15.8	920.0	3560.0			
b. External Leak						
INCIPIENT						
a. High Vibration						
b. Over-temperature						
c. Over-current						

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Confidence and Tolerance

Confidence

⇨ how well the experimentally measured parameter represents the actual parameter

Tolerance Uncertainty

⇨ Physical and environmental differences of equipment samples

⇨ Increased data sources increases tolerance uncertainty

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Data Quality

Plant Specific data is ideal, but low in confidence.

Variables cause data fluctuation

⇨ Maintenance practices
⇨ Data collection differences
⇨ Intensified preventive maintenance
⇨ Changes in process conditions
⇨ Equipment upgrades

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Failure Rate Variation

Circumstantial

Based on assumptions
⇨ Explicit
⇨ Implicit
⇨ Ignored
Failure rates are predictions

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Factors Affecting Failure Rate Variation

Equipment Boundaries
Taxonomy Level Breakdown
Process Severity
Environment
Suitability for Service
Maintenance
Data Capture

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