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LCCA – Reliability Analysis Methods Innovative techniques - Remote maintenance

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Content and objectives

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Life Cycle Cost Analysis

Reliability analysis methods (FMEA-FMECA-HAZOP-FTA-ETA)

Innovative techniques (Genetic algorithms, Fuzzy logic, Artificial neural networks)

Tele-maintenance

Objectives

Know analysis techniques and models to support the maintenance design process

Know analysis techniques and models to support decisions

LCCA

LCCA

Life Cycle Cost Analysis

Introduction

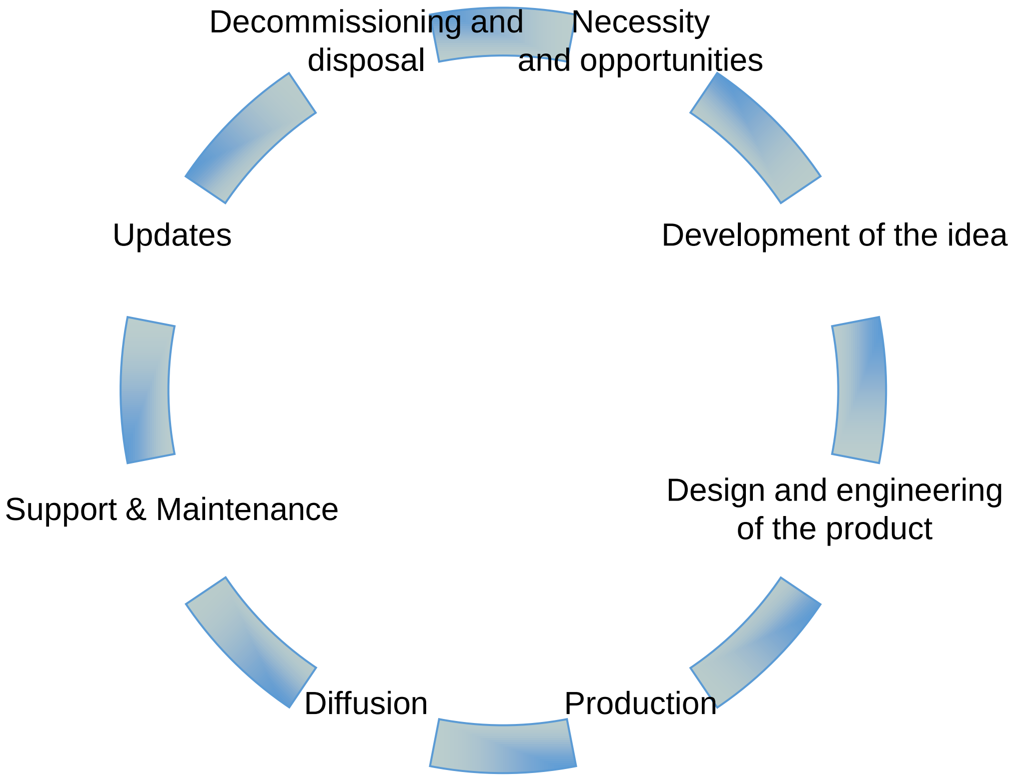
Life Cycle Cost Analysis (LCCA) is based on a systematic and analytical approach that can be used in the evaluation of alternative design hypotheses and aims to choose the alternative associated with the least use of resources and therefore of lower cost considering the entire life cycle of the system.

CUSTOMER SATISFACTION

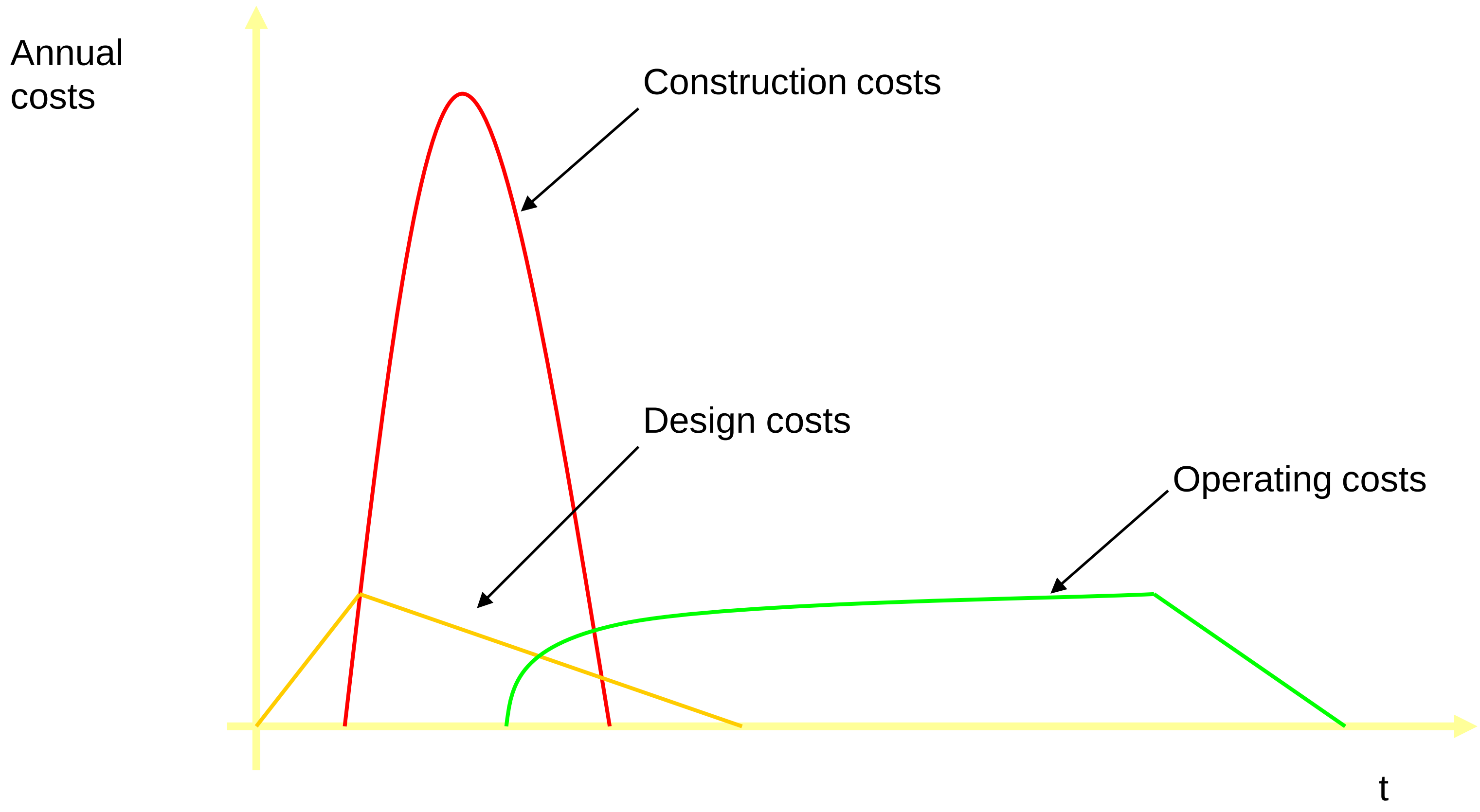
Introduction

The LCCA assesses acquisition, operation, maintenance and disposal costs and compares the initial investment with future savings, taking into account financial aspects.

Life cycle of a system



Costs of a system



LCCA

The key steps for LCC analysis are:

1. Define the problem and set goals
2. Identify viable alternatives
3. Establish the basic assumptions and parameters to be considered
4. Estimate costs and time for each alternative
5. Discounting future costs
6. Calculate and compare LCCs associated with different alternatives of the same project
7. Calculate additional measures if necessary (AIRR, NS, SIR)
8. Analyze the uncertainty of input data
9. Take into account anything that goes beyond a monetary evaluation of costs and benefits
10. Propose and recommend a decision

Lifecycle costs

Life Cycle Cost

- **Costs of acquisition**
  - Costs of Research and Development
    - Project Management
    - R&D
    - Engineering of the project
    - Development & Testing prototype
    - Engineering data
  - Investment costs non-recurring
    - Logistics and Spare parts
    - Production
    - Overheads
    - Training initial
    - Technical data
  - Investment costs Recurring
    - Parts for updating
    - Update Auxiliary
    - Integrated system of improvements
    - Improvement costs Utilities
    - Cleaning costs
- **Costs of maintenance**
  - MTZ costs Prev. and accidental
    - Manpower, materials and supervision
    - Replacement costs and renewal
    - Logistic costs
    - Modification costs of the system
    - Costs of documentation
  - Costs of management
    - Energy costs and use of the structure
    - Support costs to maintenance
    - Operating costs
    - Training
    - Operating costs Technical data
  - Costs of disposal
    - Legal costs and amm.vi disposal
    - Costs of removal
    - Operating costs disposa
    - Recovery costs
    - Cleaning costs

FMEA - FMECA

FMEA

Failure Mode Effect Analysis

FMECA

Failure Mode Effect Criticality Analysis

Introduction

Failure Mode and Effect Analysis (FMEA) and Failure Modes and Effects Analysis (FMECA) are reliability analysis methods that identify failures that have a significant impact on the performance of a system within a given application.

The FMEA technique was developed in the USA. The first document that speaks of FMEA is a military procedure Mil-P-1629 of 1949.

Introduction

Standard CEI 56-1

Analysis methods for the reliability of systems.

Failure Mode and Effect Analysis Procedure (FMEA)

MIL-STD 1629 A

Procedures for Performing a Failure

Modes, Effects, and Criticality

Analysis

Introduction

Performing a criticality analysis is used to quantify the criticality of a failure effect and estimate the probability of the occurrence of its failure mode.

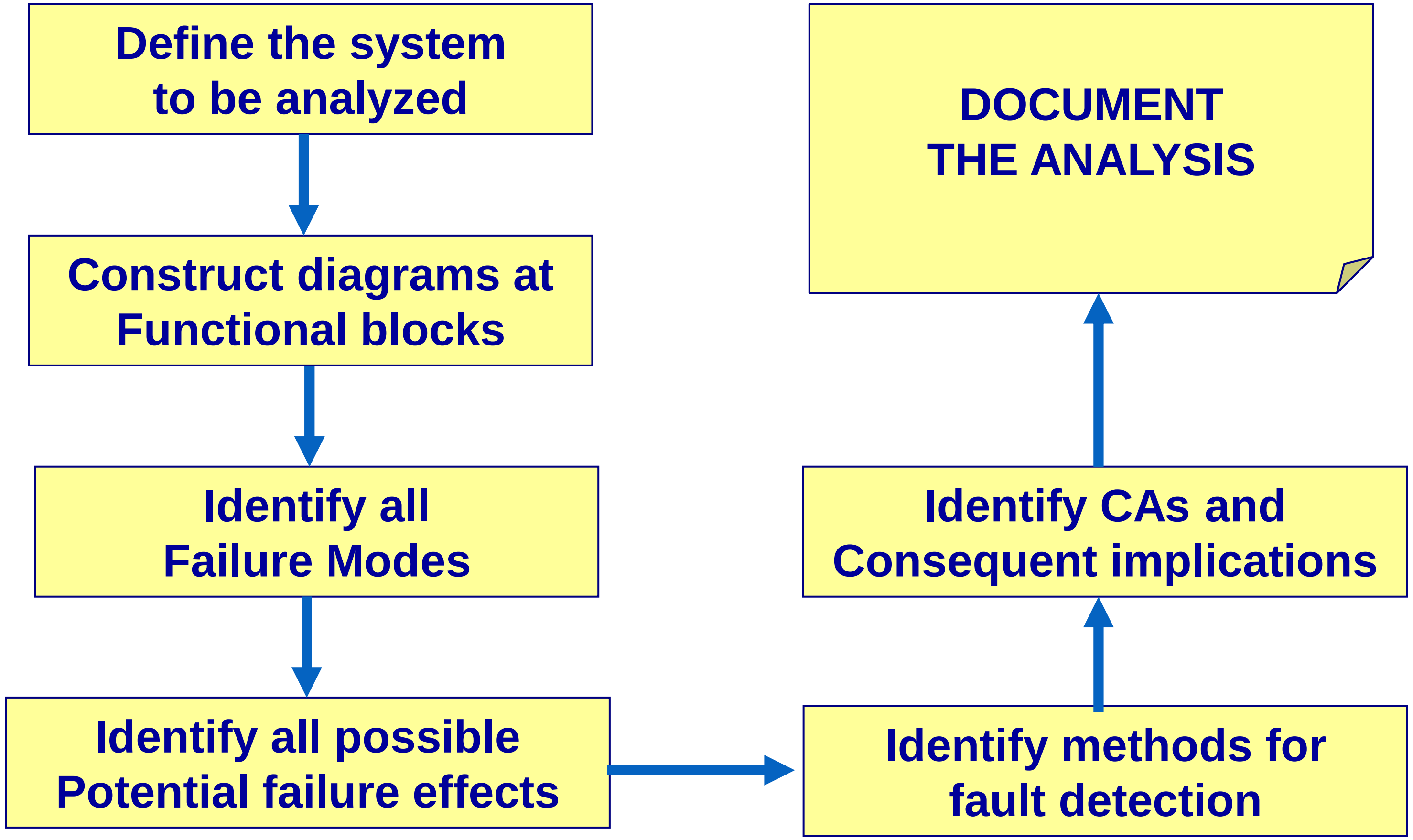
Quantifying the criticality and probability of a failure allows you to choose the corrective actions to be taken, their priority and to establish the demarcation between an acceptable criticality and an unacceptable one.

FMEA

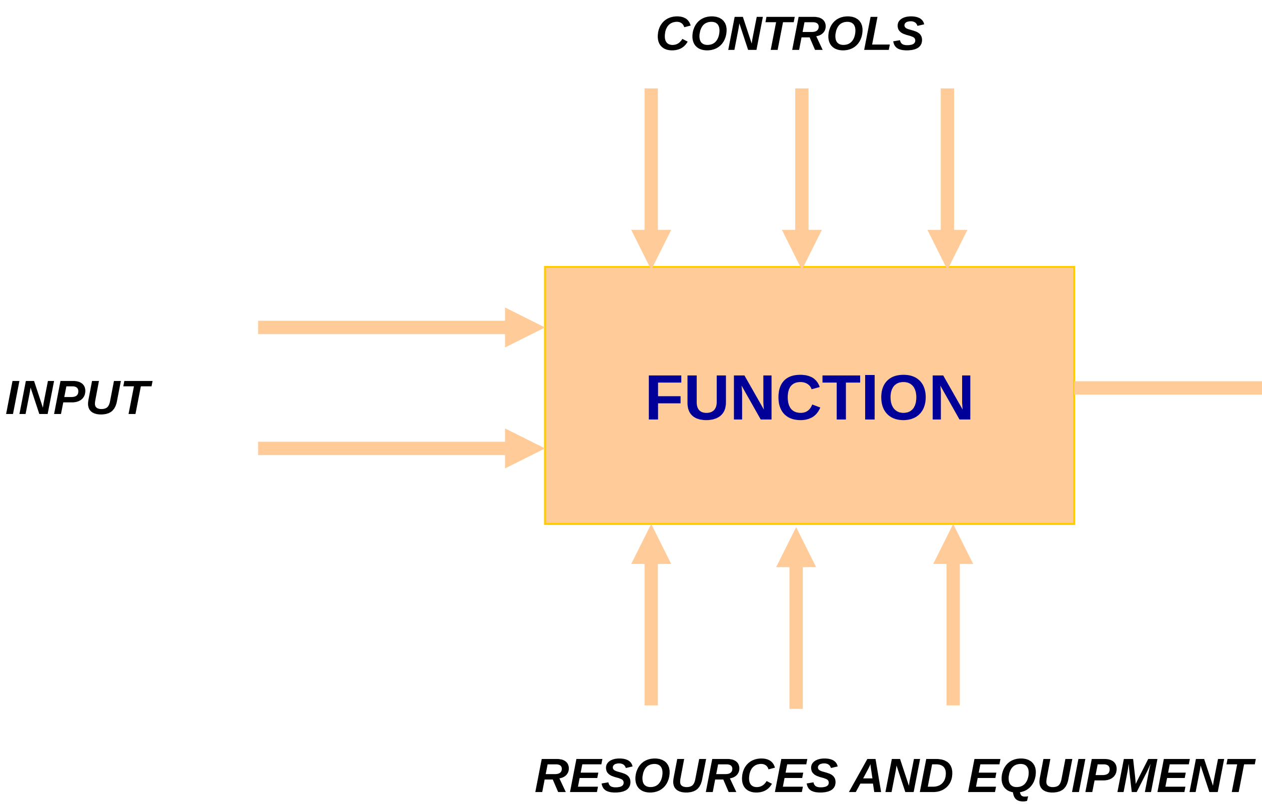
La metodologia FMEA trova applicazione in tre casi principali:

- *Nuovi progetti, nuove tecnologie, nuovi processi*
- *Modifiche a progetti o processi esistenti*
- *Impiego di un progetto o processo esistente in un nuovo ambiente, contesto operativo o applicazione*

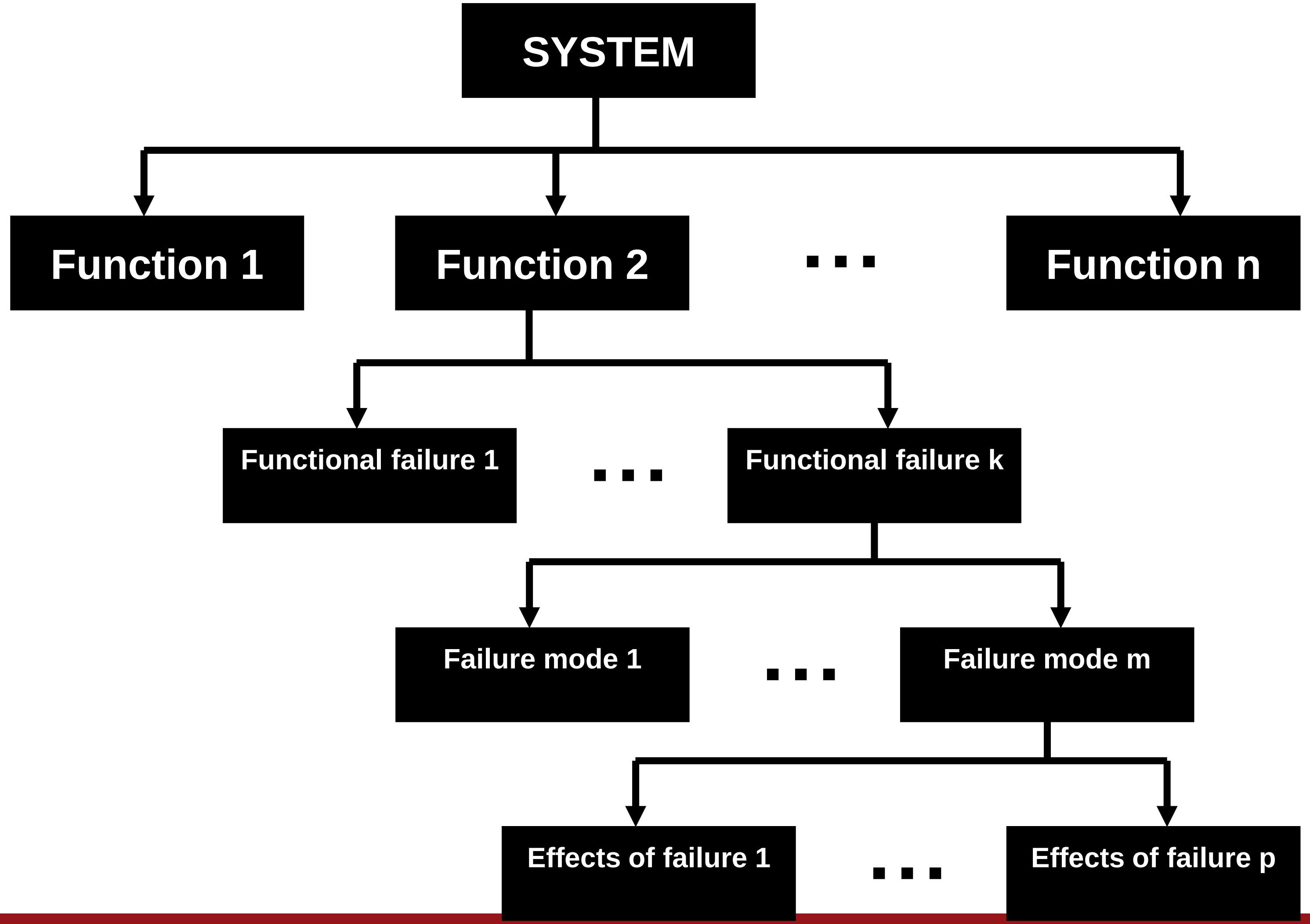
Flowchart - FMEA



FBD Elementary



Arborescence of FMEA



FMECA

FMECA analysis is an evolution of FMEA to which is added, in cascade, a pseudo-quantitative procedure of Criticality Analysis.

FMECA

Component	Failure Mode	Failure effect	Cause of the failure	Presence of preventive signal	Breakdown: Hidden Evident	MTBF	**O**	**S**	**D**	**RPN**	AC Maintenance option

Occurence Rating

Severity Rating

Detectability Rating

Risk Priority Number = O x S x D

FMECA – RPN

RPN (Risk Priority Number) = Occurence x Severity x Detectability

[Criticality = Probability x Severity x Difficulty of Detection = PGI]

	1 punto	10 punti
Occurence (probabilità)	Rare	Frequent
Severity (Gravità)	Negligible	Death
Detectability (Difficoltà di individuazione)	Easy	Difficult

FMECA – Modi di guasto

Possible failure modes. Proposed list IEC 56-1:

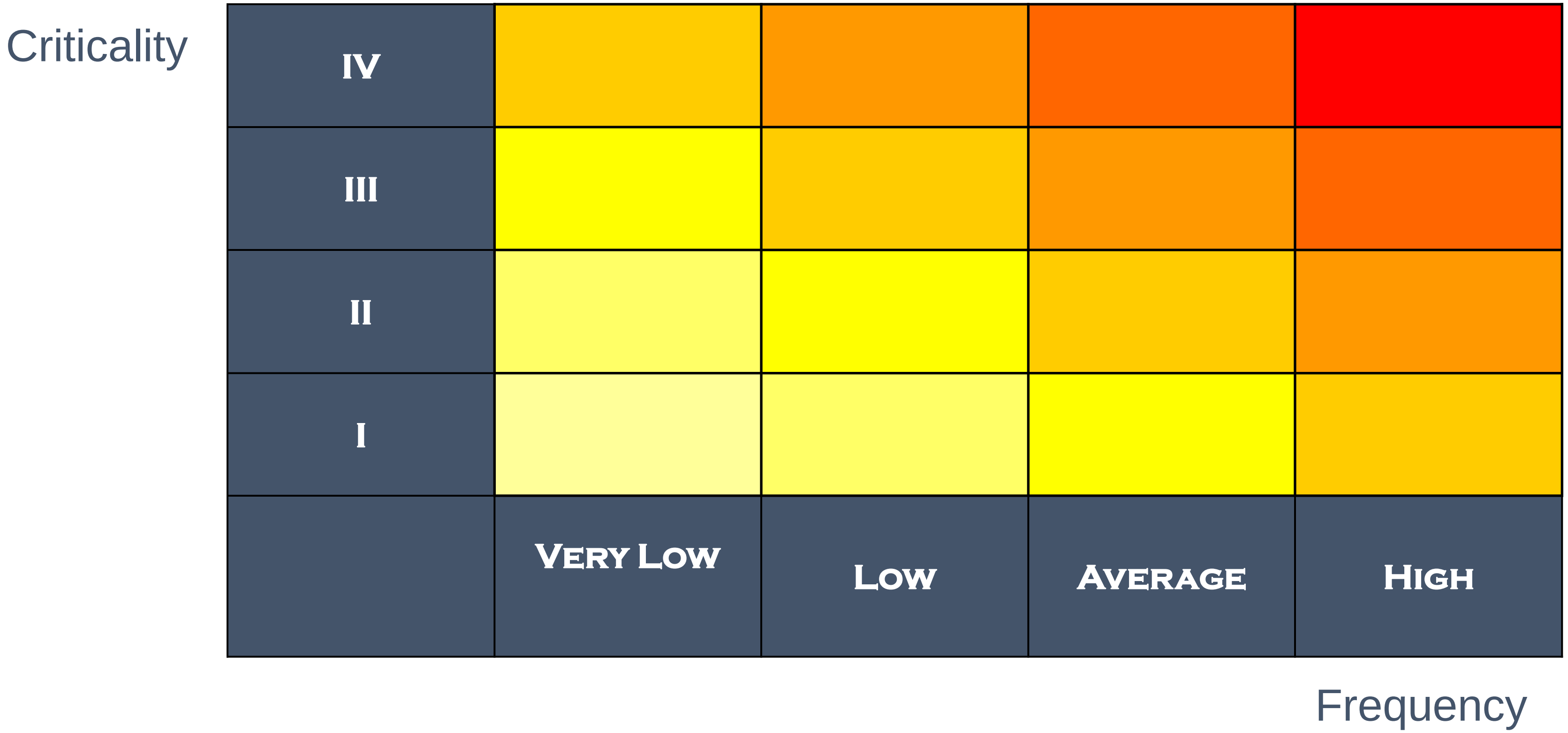
1.Structure failure	18. Incorrect activation
2. Seizure or jamming	19. It doesn't stop
3. Vibration	20. Does not start
4. Does not stay in place	21. Does not switch
5. Does not open	22. Premature intervention
6. Does not close	23. Delayed intervention
7. Remains open	24. Incorrect entry (excessive)
8. Remains closed	25. Incorrect input (insufficient)
9. Inward loss	26. Incorrect output (insufficient)
10. Outward loss	27. Wrong output (excessive)
11. Out of tolerance (more)	28. Lack of entrance
12. Out of tolerance (less)	29. Lack of exit
13. Works even when it shouldn't	30. Short circuit (electrical)
14. Intermittent operation	31. Open circuit (electric)
15. Irregular operation	32. Dispersion (electric)
16. Incorrect indication	33. Other exceptional failure conditions depending on system characteristics, operating conditions and operating constraints
17. Reduced flow	

FMECA – Criticality analysis

Criticality - Table proposed by CEI 56-1:

Criticality level	**Conditions that define criticality**
I	Any event likely to impair the proper functioning of the system, causing negligible damage to the system or the surrounding environment without presenting a risk of death or impairment.
II	Any event that impairs the proper functioning of a system without, however, causing significant damage to the system or presenting a significant risk of death or impairment.
III	Any event that could cause the loss of essential functions of the system causing significant damage to the system or its environment, but with a negligible risk of death or impairment.
IV	Any event that could cause the loss of essential functions of the system causing significant damage to the system or its environment and/or that could cause death or impairment.

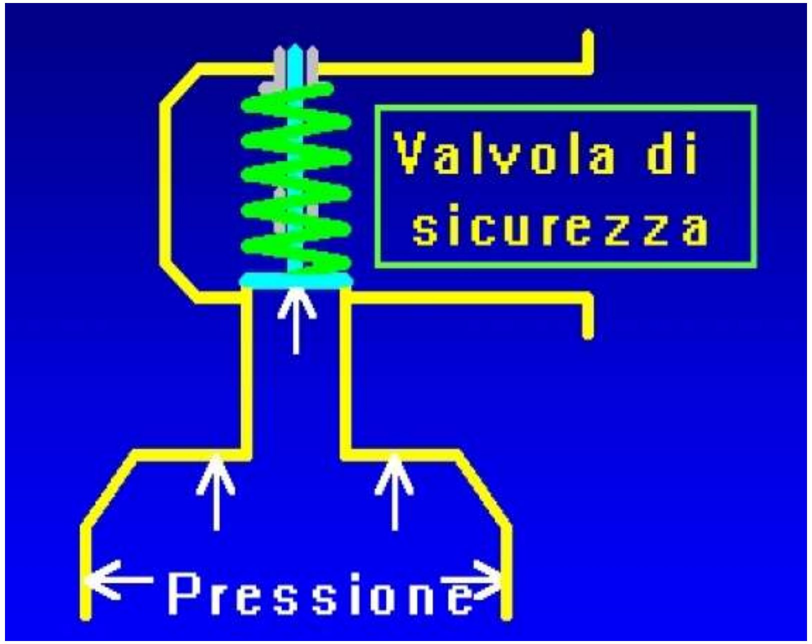
FMECA – Grid of critical issues



FMECA – Example

Example

FMECA analysis of a Spring Safety Valve.



FMECA – Example

[RPN (Risk Priority Number) = Occurence x Severity x Detectability]

	1 punto	10 punti
Occurence	Rare	Frequent
Severity	Negligible	Death
Detectability	Easy	Difficult

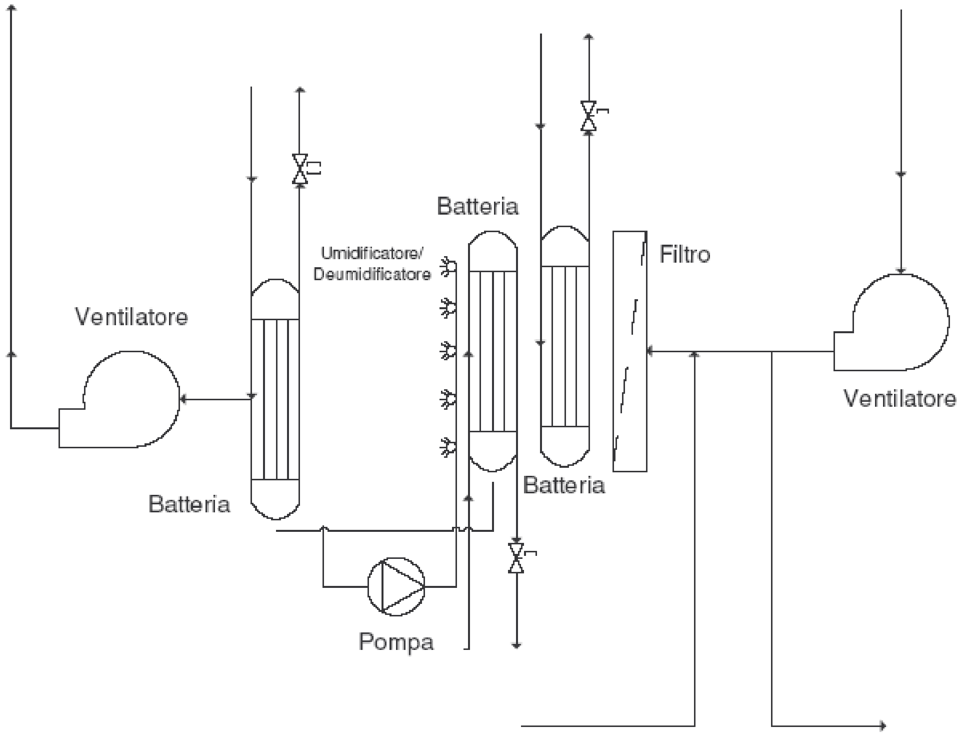
FMECA – Esempio

Component: Safety Valve Situation: Valve closed, normal conditions						
Function	**Failure modes**	**Causes**	**Criticality**			**PGI**
			P	**G**	**I**	
Closed $p<p_{amm}$	Does not close completely	Various	3	1	1	3
Open $p>p_{amm}$	Does not open	Calibration error	1	10	5	50
………	………..	………..	..	…	..	…..

FMECA – Example

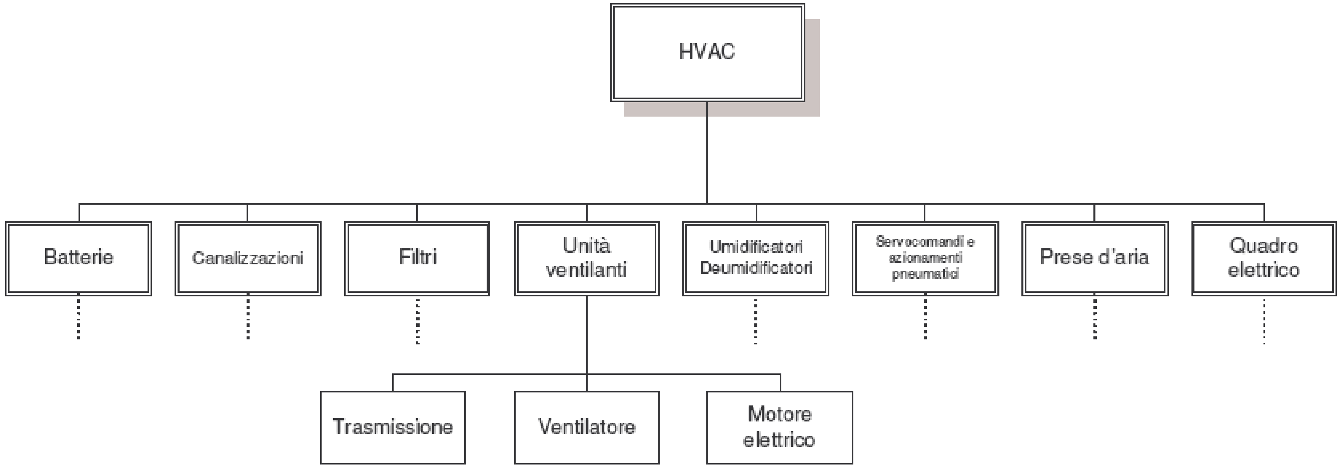
Example

FMECA analysis of the subsystem - ventilating units with mechanical belt / pulley transmission - of an Air Conditioning System



FMECA – Example

Il primo passo consiste nell'individuazione dei componenti e degli elementi che costituiscono il sottosistema delle unità ventilanti.



Il sottosistema è scomposto nei seguenti componenti:

- Trasmissione (cinghia/puleggia)
- Ventilatore
- Motore elettrico

FMECA – Example

FMECA	ID IMPIANTO		
	Docum. Tecnica:		Modello
	Descrizione:	impianto di condizionamento	Tipo

Sottosistema	Componente / Elemento	GUASTO – Tipo	GUASTO – Effetto	GUASTO – Causa	Deterioramento caratteristiche	Allarmi preventivi	E/N	Occurence (O)	Severity (S)	Detectability (D)	RPN	MTZ
1.1 Unità ventilanti												
	1.1.1 Trasmissione	slittamento cinghia	portata aria insufficiente	usura	si	Rumore	E	6	6	2	72	CBM
		rottura cinghia	portata aria nulla	usura	si	Deterioramento cinghia, deposito gomma	E	5	6	1	30	CBM
		rottura cinghia	portata di aria nulla	errato assemblaggio	si	no	E	2	6	2	24	GUASTO
		rottura puleggia	portata di aria nulla	difetto di fabbrica	si	no	E	1	8	2	16	GUASTO
		usura cinghia/puleggia	diminuzione della velocità di rotazione	assemblaggio fuori centro	si	Sibilo	N	5	5	2	50	CBM
		deterioramento cuscinetti	variazioni di velocità e vibrazioni	usura	si	Vibrazioni Rumore	N	3	5	2	30	PREV
	1.1.2 Ventilatore	portata aria insufficiente	riduzione efficienza impianto	ostruzioni, filtri sporchi	si	Sensori locali	N	8	6	2	96	CBM
		portata aria eccessiva	riduzione efficienza impianto	problemi nel circuito di aspirazione	si	Sensori locali	N	5	6	2	60	CBM
		rottura pale	variazione della portata	velocità, usura	si	no	N	3	8	3	72	PREV
		sporcamento pale	riduzione efficienza	mancato filtraggio aria	si	no	N	5	6	3	90	CBM
		deformazione pale	riduzione efficienza	sovraccarico	si	no	N	3	6	4	72	PREV
		deterioramento cuscinetti	instabilità	usura	si	Vibrazioni Rumore	N	3	7	2	42	PREV
		pulsazione d'aria	instabilità della portata	instabilità in ingresso	si	Vibrazioni Rumore	N	3	5	2	30	GUASTO
		foratura chiocciola	riduzione efficienza	erosione	si	no	E	2	6	2	24	GUASTO

FMECA – Example

Sottosistema	Componente / Elemento	GUASTO			Deterioramento caratteristiche	Allarmi preventivi	E/N	Occurence (O)	Severity (S)	Detectability (D)	RPN	MTZ
		Tipo	Effetto	Causa								
	1.1.3 Motore elettrico	variazione di tensione di alimentazione	motore fermo	erogazione energia elettrica	si	no	N	4	8	2	64	GUASTO
		mancanza fase	motore bruciato	usura contatti	si	usura surriscaldamento	E	4	9	2	72	CBM
		variazione di velocità	variazione portata	variazione tensione di alimentazione	no	tensione bassa	N	5	6	3	90	CBM
		bloccaggio	bruciatura avvolgimenti	rottura cuscinetti	si	Vibrazioni Rumore	N	3	9	3	81	CBM
		surriscaldamento avvolgimenti	bruciatura avvolgimenti	Polvere, sporcizia	si	aumento temperatura olio	N	4	9	2	72	PREV
		surriscaldamento avvolgimenti	motore bruciato	sovraccarico continuativo	si	no	N	2	9	3	54	GUASTO
		surriscaldamento avvolgimenti	motore fermo	sovraccarico accidentale	si	no	N	2	7	3	42	GUASTO
		corrente non equilibrata	motore fermo	usura contatti	si	surriscaldamento	N	5	7	2	70	CBM
		variazione di velocità	variazione portata	difetto inverter	si	sistema di controllo	N	4	6	3	72	GUASTO
		scintillio	rischio incendio	allentamento avvolgimenti	no	no	N	2	10	3	60	GUASTO
		difficoltà di avviamento	coppia di spunto insufficiente	bassa tensione di alimentazione	si	tensione bassa	N	2	7	3	42	GUASTO
		cortocircuito	innesco incendio	rottura avvolgimenti	si	no	E	2	10	2	40	GUASTO

HAZOP

HAZOP

HAZard and OPerability analysis

Introduction

The HAZOP (Hazard and Operability Analysis) is a qualitative analysis that allows to highlight how a system may not correspond to the expected behavior in the design phase.

Introduction

HAZARD: any situation that may cause a catastrophic release of toxic, flammable or explosive chemicals or any event that may result in injury to personnel

OPERABILITY: any situation that may produce a shutdown of the plant with a consequent violation of the conditions of respect for the environment, safety and health of the operators and that may finally have negative repercussions on profitability

HAZOP

The methodology is based on the work of a team of experts with different scientific-cultural backgrounds and is carried out in a series of meetings following a pre-established structure, dictated by the experience of the team leader and the guiding words.

HAZOP

The process is systematic and structured through precise terminology:

Nodes: these are the points (of pipes, instrumentation or procedures) where parameter deviations are analyzed

Intention: defines how the system must operate in the intentions of the designer

Deviation: it is the departure from the intention

Causes: these are the reasons that induce deviations

HAZOP

***Consequences:* are the events that can happen due to deviations**

***Guiding words:* they are simple words that are used to qualify or quantify an intention, they are used in order to highlight the situation effectively and to stimulate the process to discover deviations. It is often necessary to adapt the guide words to the parameters under consideration**

HAZOP – Implementing rules

The HAZOP analysis can be divided into five phases:
Definition of the purpose and objectives of the study

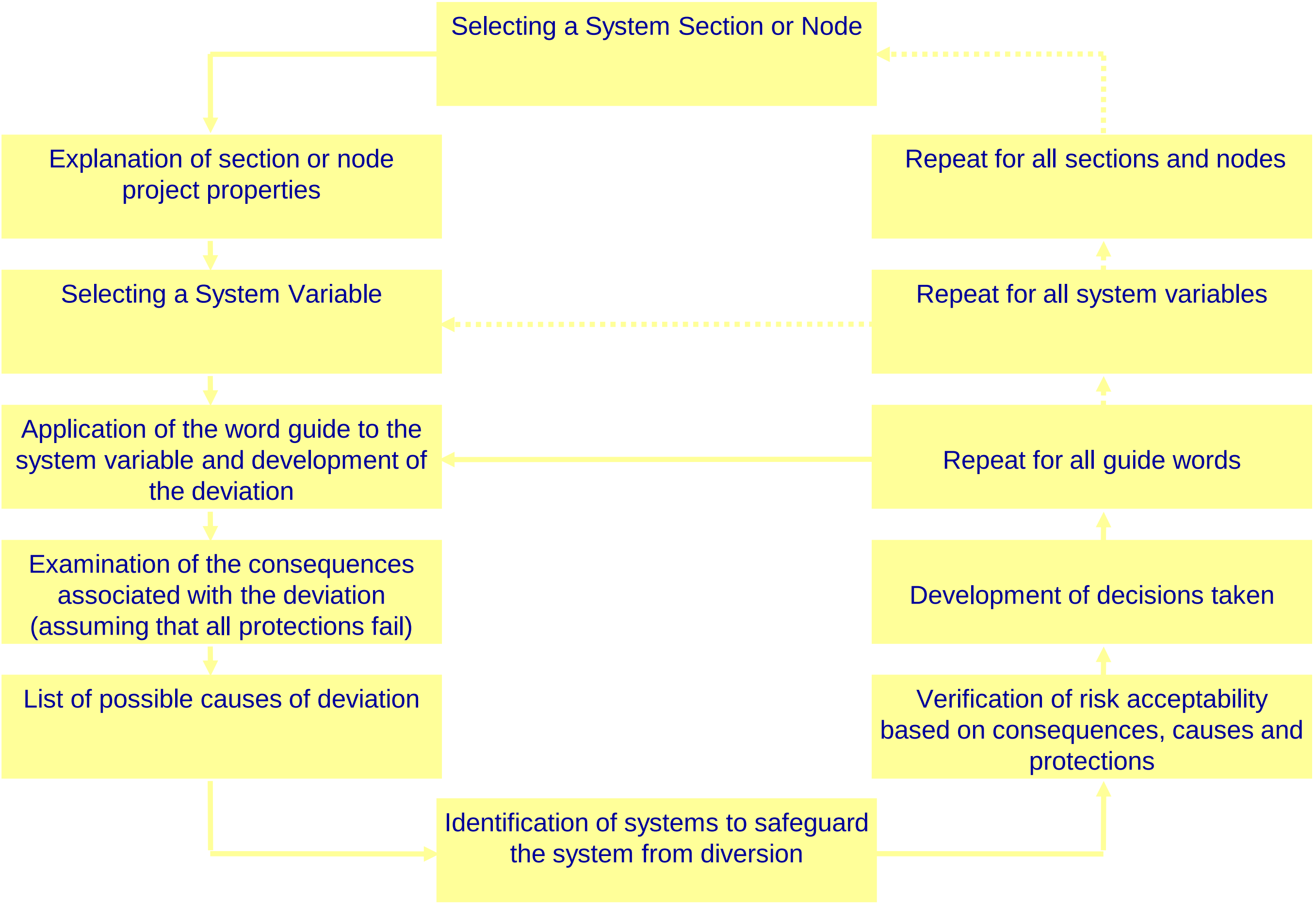
Team selection

Preparation of the study

Running the analysis

Recording of results

HAZOP – Flowchart



HAZOP – Performing the Analysis

- In the preliminary analysis the plant is divided through a series of nodes
- The HAZOP analysis is carried out by applying the guide words to the parameters that characterize the nodes; The guide words must be applied one by one, to all parameters, for each node
- The choice of the sequence of nodes is carried out following the flow of the process
- The guide-parameter word combination identifies the deviation, which may or may not be real; if it is not real we proceed further, if instead it is real we move on to the investigation of the causes that can cause it and the consequences it can entail
-

HAZOP – Use of Keywords

Typically, industrial plants use a restricted group of guiding words that consists of the following expressions:

No: denial of intention, neither intention nor anything else is realized

Major: Quantitative Increase

Minor: quantitative decrease

Also: quantitative increase, not only the intention is realized but further favorable conditions

Part of: qualitative decrease, only part of the intention is achieved

inverse: the logical opposite of the intention is realized

different: the intention is not realized, even partially, but something quite different happens

HAZOP – Use of Keywords

When it is important to also consider the time parameter, additional guiding words are needed, which typically are:

Soon: something happens sooner than expected

Late: something happens later than expected

Before: something happens earlier than the expected sequence

After: something happens later than the expected sequence

HAZOP – Use of Keywords

Keyword + Parameter/Function = Potential Deviation

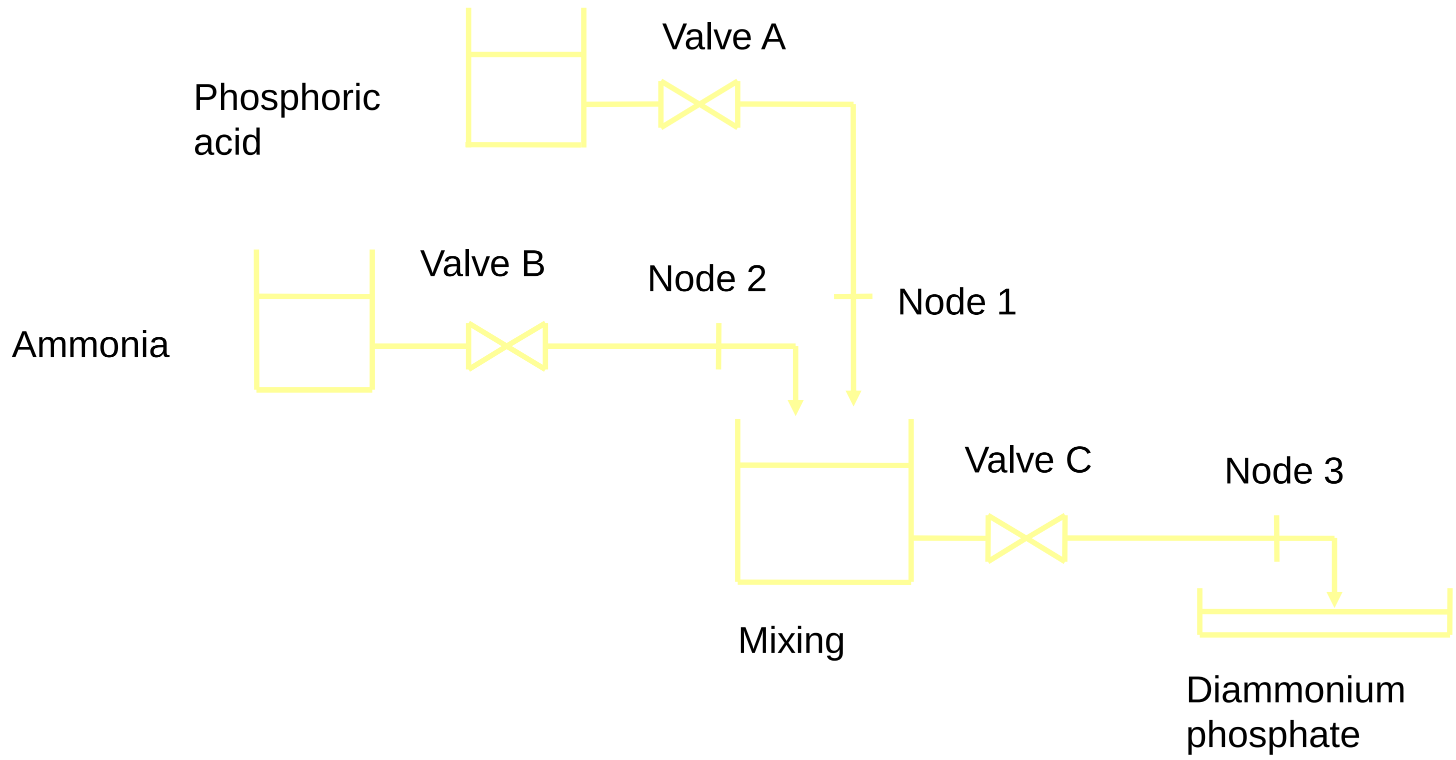
example

NO + Flow = No Flow

HAZOP – Recording Results

Example

Diammonium phosphate production plant:



HAZOP – Recording Results

Comp. n°	Deviazione	Cause	Conseguenze	Sistemi di sicurezza	Azioni da intraprendere
1.1	**No & portata** (nessuna portata al nodo 1)	-la valvola A è chiusa -l'acido fosforico di reattore è esaurito -rottura nel tubo o il tubo è otturato	eccesso di ammoniaca nel reattore e perdita nell'area di lavoro (fuoriuscita di vapori di ammoniaca)		chiusura automatica della valvola B per bassa portata di acido fosforico
1.2	**Less & flusso** (diminuzione di portata al nodo 1)	-valvola A parzialmente chiusa -parziale otturazione o perdite nel tubo	eccesso di ammoniaca nel reattore e perdita nell'area di lavoro. Tale perdita dipende dalla diminuzione di portata nell'alimentazione di acido fosforico		chiusura automatica della valvola B se la portata nel tubo di mandata dell'acido fosforico è ridotta. Il set-point viene calcolato in base alla tossicità calcolata come funzione della riduzione di portata dell'acido fosforico
1.3	**More & flusso** (al nodo 1 la portata aumenta)		non presenta alcun rischio		

HAZOP – Recording Results

Comp. n°	Deviazione	Cause	Conseguenze	Sistemi di sicurezza	Azioni da intraprendere
1.4	**Part of & portata** (diminuisce la concentrazione di acido fosforico al nodo 1)	- fornitura di pessimi materiali - errore nel caricamento del serbatoio di stoccaggio dell'acido fosforico (l'acido fosforico usato è già alla più alta concentrazione disponibile sul mercato)	vedi 1.2		provvedere ad un controllo della concentrazione di acidi fosforico nel serbatoio dopo la procedura di carica
1.5	**As well as & portata** (incremento della concentrazione di acido fosforico)				
1.6	**Reverse & portata** (flusso contrario al nodo 1)	- pessime forniture di componenti - errato reagente immesso nell'impianto	nessuna condizione perché il flusso possa essere inverso		
1.7	**Other than & portata** (diverso reagente nella linea A)		dipende dalla sostituzione. Il team deve studiare la pericolosità di questo evento sulla base degli altri reagenti, disponibili nel complesso, di caratteristiche simili		check sui materiali scelti prima di caricare l'acido fosforico nel serbatoio

FTA - ETA

FTA

Fault Tree Analysis

ETA

Event Tree Analysis

FTA - Introduction

FTA (Fault Tree Analysis) is a deductive technique that allows you to identify the possible combinations of events that can lead the plant or system into an unwanted state. Of these feared and dangerous top events, the possible causes are sought and the probability of occurrence is determined.

FTA – Implementing rules

The realization of an FTA analysis involves a procedure that is divided into the following steps:

1. **Identification of the undesirable event (Top Event)**
2. **Construction of the fault tree**
3. **Tree analysis**

FTA – Construction of the FT

The steps for the construction of the FT are:

- Define the objective of the analysis
- divide the system into sub-systems
- Describe each sub-system
- define the Top Event
- determine the causes of the Top Event (fault events)
- determine a cause for each Top Event fault event
- Repeat the previous step until all fault events have been defined at the lowest level of analysis (i.e. up to the base event)

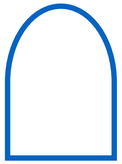
FTA – Construction of the FT

The fundamental elements for the construction of the tree are, therefore, the logical gates and the events that are reported using graphic schematizations that facilitate the use and understanding of the tree itself.

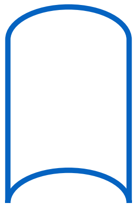
FTA – Logic gates

Examples of logic gates used:

AND ports: represent the occurrence of the output event only when all input events occur



OR ports: represent the occurrence of the output event when at least one of the input events occurs

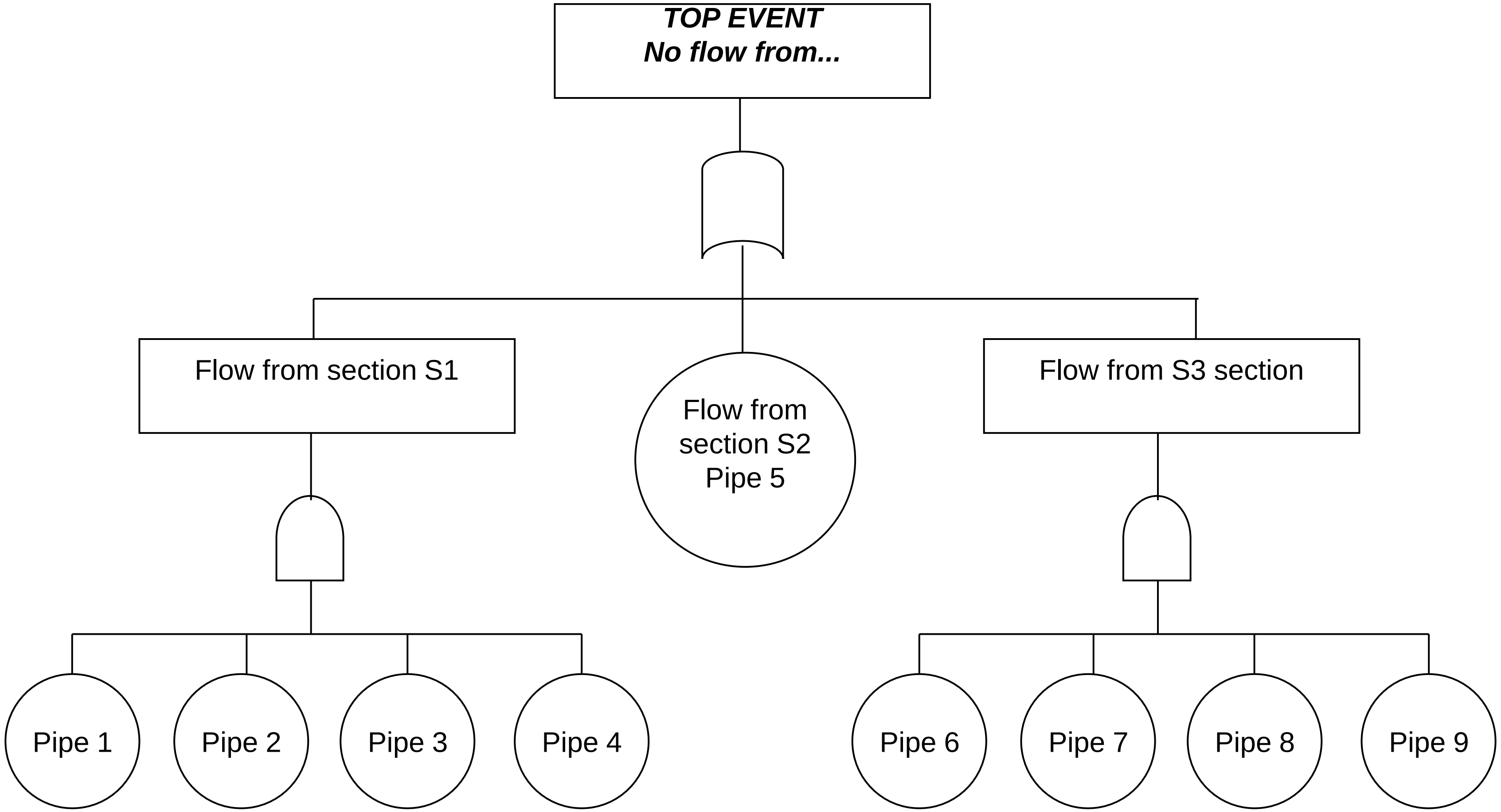


FTA – Events

The events are summarized as follows:

- BASE EVENT: it is a starting (basic) fault for which no further details are needed
- USUAL EVENT: its occurrence is normally expected
- PRIMARY EVENT: it is not developed in a chain of events because it has little consequence and there is not enough information available
- TOP EVENT: the undesirable event whose consequences are serious and to be avoided

FTA – FT example



FTA – FT Analysis

At the end of the construction of the tree, the "cut-sets" are identified, defined as a combination of events that cause the top event.

At this point it is possible to carry out the qualitative and quantitative analysis of the tree.

FTA – FT Analysis

In general, we proceed according to the following points:

- Determine the "smallest" cut-sets to simplify the tree
- Determine the probability of each input event
- Combine the probability of input to logic gates
- Continue to combine the probability of inputs until the probability of the Top Event is determined

FTA – FT Analysis

Once the qualitative analysis has been completed, which allows, through the use of Boolean algebra, to determine the minimal cut-sets, we proceed with the quantitative analysis.

To carry out the quantitative analysis it is necessary to obtain information from different sources to arrive at the determination of the reliability and unreliability of the event under examination.

FTA – FT Analysis

To improve the system under analysis, all components with a high probability of failure must be examined to make the appropriate corrections. For example,:

Replacement of some critical components

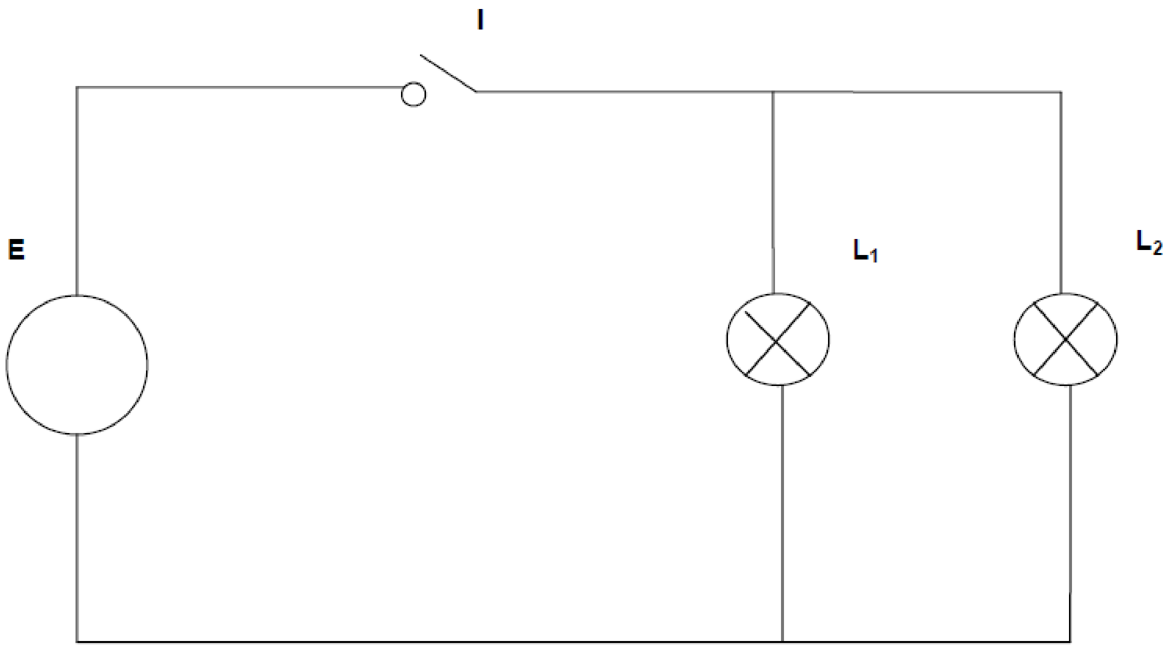
Changing the System Configuration

Adding redundant elements

Planning of periodic maintenance interventions for the scheduled replacement of critical elements

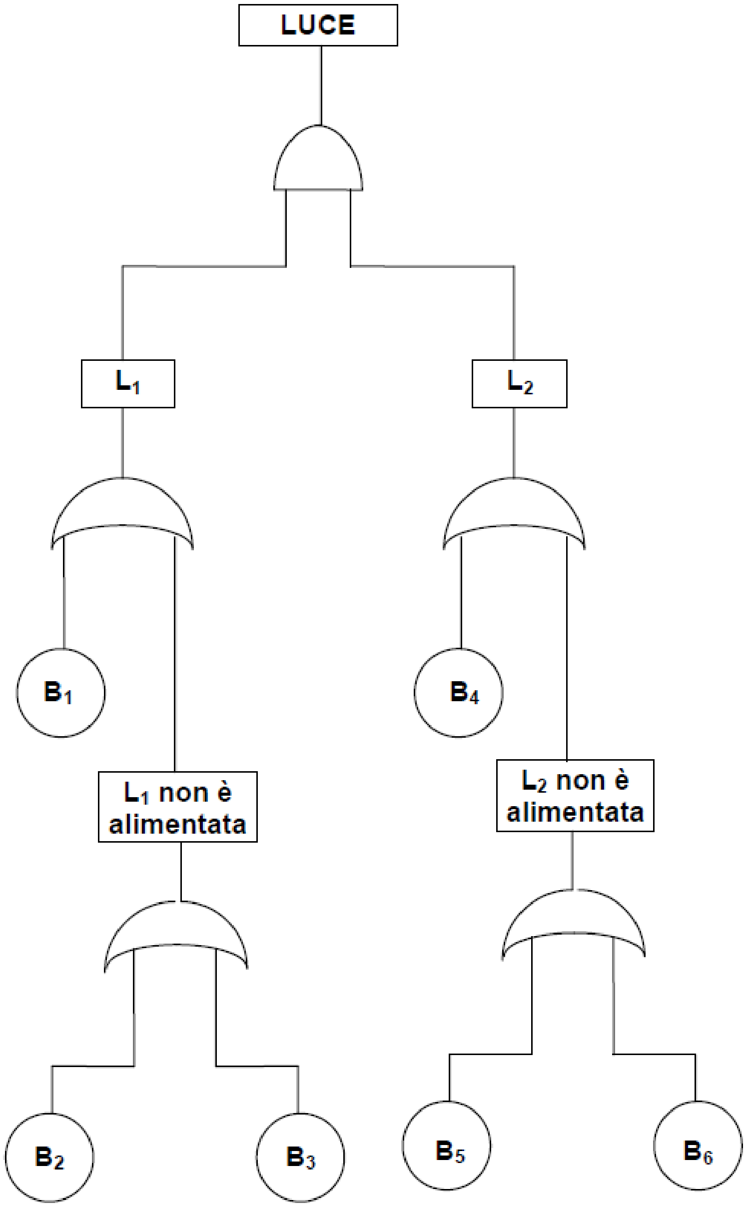
etc.

FTA

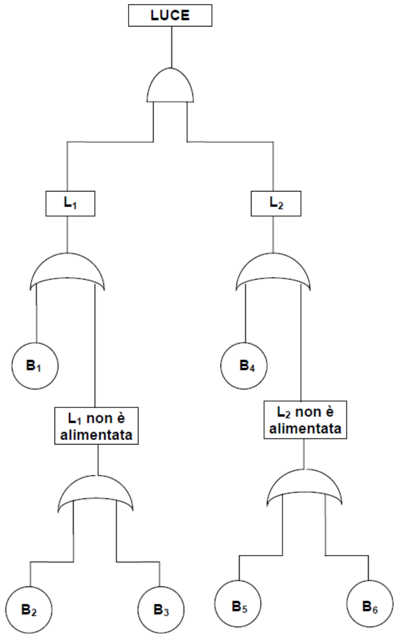


FTA

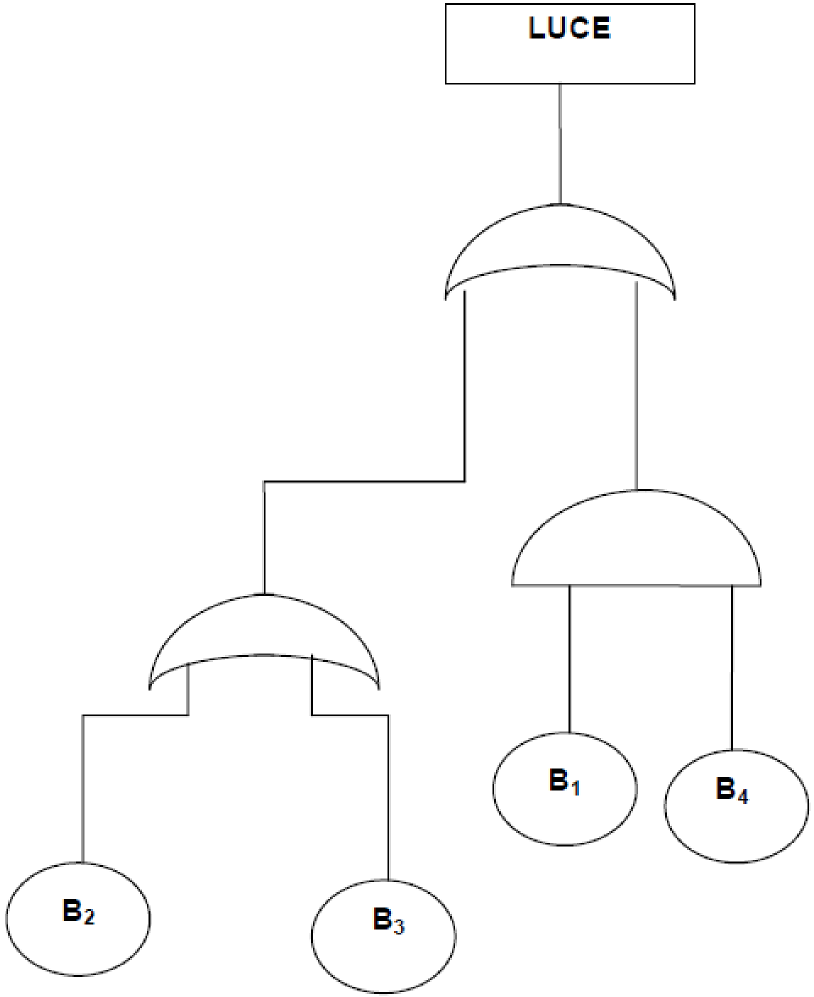
- B_1 = LAMPADA L_1 GUASTA;
- B_2 = B_5 = INTERRUTTORE GUASTO;
- B_3 = B_6 = GENERATORE GUASTO;
- B_4 = LAMPADA L_2 GUASTA.



FTA



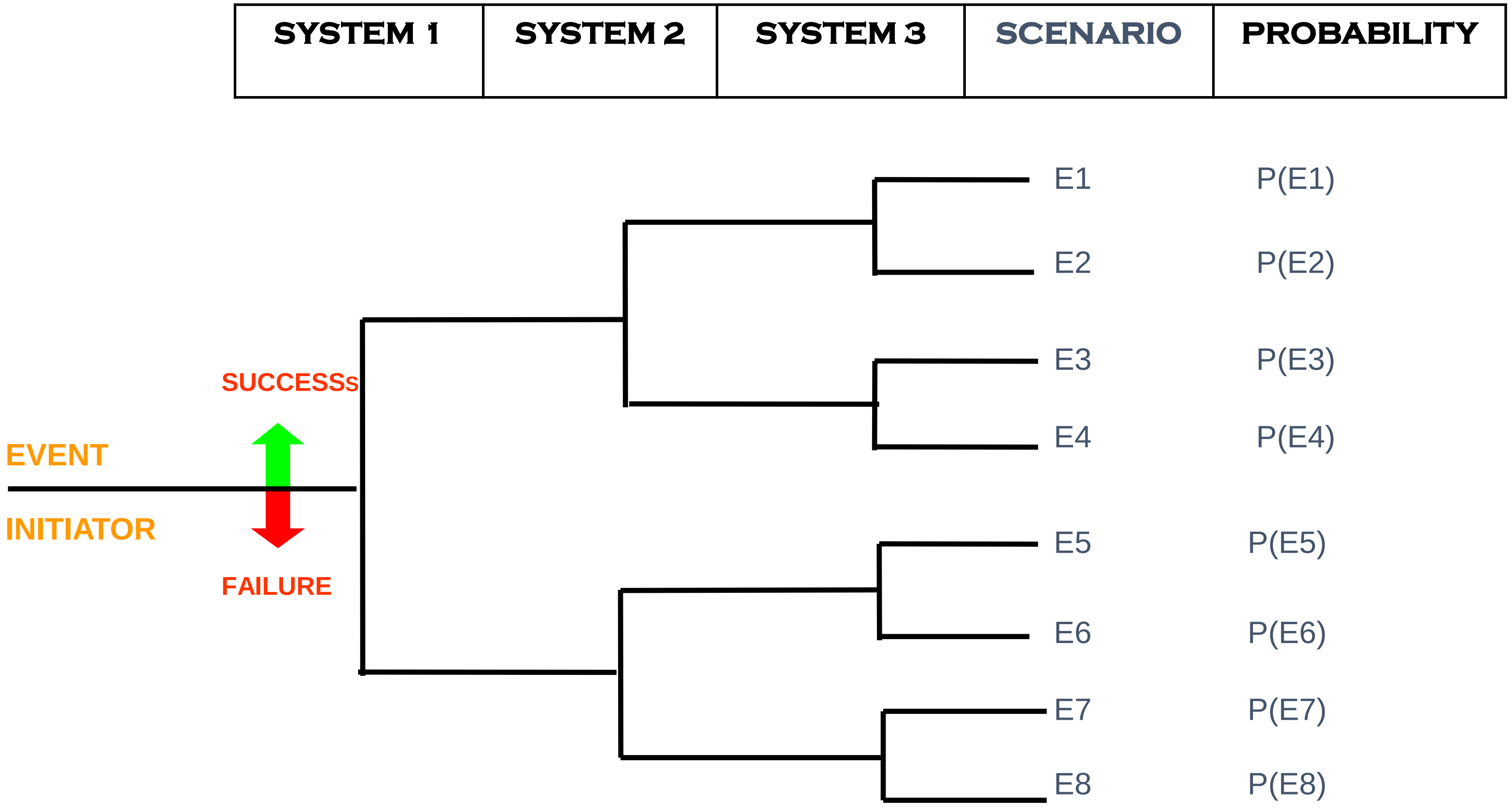
- B_1 = LAMPADA L_1 GUASTA;
- B_2 = B_5 = INTERRUTTORE GUASTO;
- B_3 = B_6 = GENERATORE GUASTO;
- B_4 = LAMPADA L_2 GUASTA.



ETA - Introduction

The ETA (Event Tree Analysis) is an inductive logical methodology that originates from applications in the economic and financial field and which has also been used in the industrial field to highlight all the possible accident scenarios deriving from the evolution of an initiator event, in relation or not to the intervention of systems responsible for the protection of the plant, the external environment and personnel.

ETA – Esempio di ET



ETA – Implementing rules

The generic leaf of the tree represents a possible scenario that would occur at a particular combination of events. The probabilities that characterize each node are conditional probabilities and therefore must be defined in relation to the situation that has emerged in the nodes preceding the one under examination.

In the calculation phase, the probability of the single scenario is represented by the simple product of the probabilities found on the branches that connect the leaf with the top event.

ETA – Implementing rules

The ETA analysis is divided into 4 phases:

1. Identification of initiator events
2. Identification of safety functions involved in incident sequences
3. Tree development
4. Analyzing Incidental Sequence Results

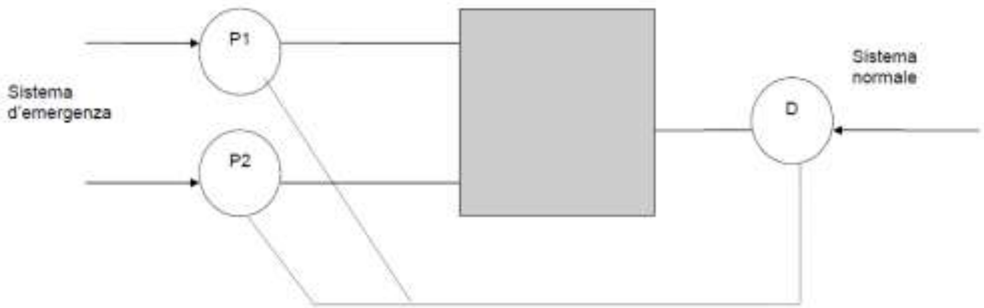
ETA – Identification of initiating events

The definition of events can be the result of a technological assessment based on a risk analysis carried out previously, on incidents that have occurred and in any case on the experience and sensitivity of the analyst.

The main classes of initiating events concern:

- breakage or failure of components or systems
- human errors
- processes that have not taken place, or that may give rise to adverse effects
- malfunctions of structures
- external causes

ETA

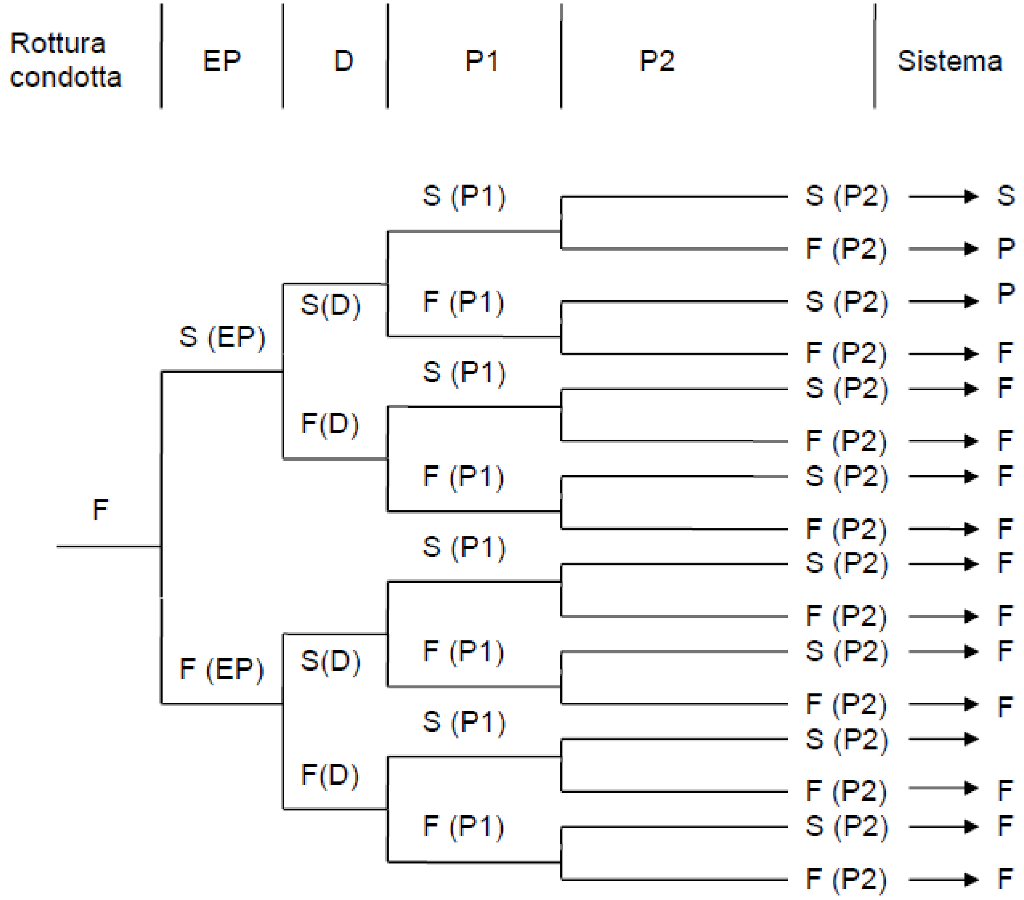


Il componente EP (Electric Power) tiene conto della presenza o meno di corrente elettrica.

Si è ipotizzato che per una corretta operatività del sistema di raffreddamento ausiliario sia richiesto il funzionamento di entrambe le pompe; per questo motivo nell'albero rappresentato risultano tre tipi di eventi in uscita:

- S, success - entrambe le pompe funzionanti
- P, partial success - una sola pompa funzionante
- F (failure - entrambe le pompe guaste).

ETA


Rottura condotta
EP
D
P1
P2
Sistema
S (P1)
S (P2)
S
F (P2)
P
S(D)
F (P1)
S (P2)
P
S (EP)
F (P2)
F
S (P1)
S (P2)
F
F(D)
F (P2)
F
F (P1)
S (P2)
F
F
F (P2)
F
S (P1)
S (P2)
F
F (P2)
F
F (EP)
S(D)
F (P1)
S (P2)
F
F (P2)
F
S (P1)
S (P2)
F(D)
F (P2)
F
F (P1)
S (P2)
F
F (P2)
F

ETA – Identification of safety functions

In the identification and evaluation of safety functions, only two possibilities are considered, their success or failure.

Typically, security features include:

Safety systems

Alarm systems

Actions of operators required by procedures in case of alarm

Innovative techniques

INNOVATIVE TECHNIQUES

Artificial neural networks

Genetic algorithms

Fuzzy Logic

Soft Computing

Soft Computing techniques are algorithm-based data processing methodologies that are not limited to simply processing the information they receive, but create other algorithms and procedures suitable for this task.

In practice, we can talk about meta-algorithms capable of generating the algorithms necessary for the processing of the data submitted to them.

Soft Computing

Soft Computing techniques are:

Genetic algorithms

Fuzzy logic

Artificial neural networks

"Hybrid" techniques

Other techniques (Bayesian theory, Fractal theory, Chaos theory, etc.)

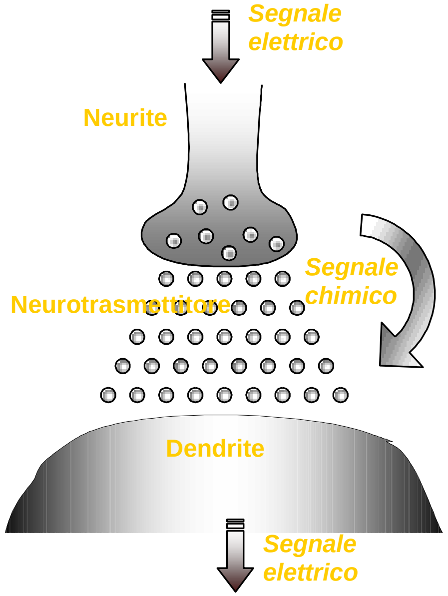
Artificial neural networks

RNAs are "adaptive" data processing systems that can, after a period of "training", classify data or model a system. Training leads to the definition of functions, within the network, that process information.

Reti neurali artificiali

HUMAN NEURON

BIOLOGICAL ANALOGY



s	**segnale proveniente dal neurite**
w	**peso della sinapsi**
$p=w \cdot s$	**segnale che attraversa il dendrite**

Artificial neural networks

s_1 s_2 $\dots$ s_i $\dots$ s_m

w_1 w_2 $\dots$ w_i $\dots$ w_m

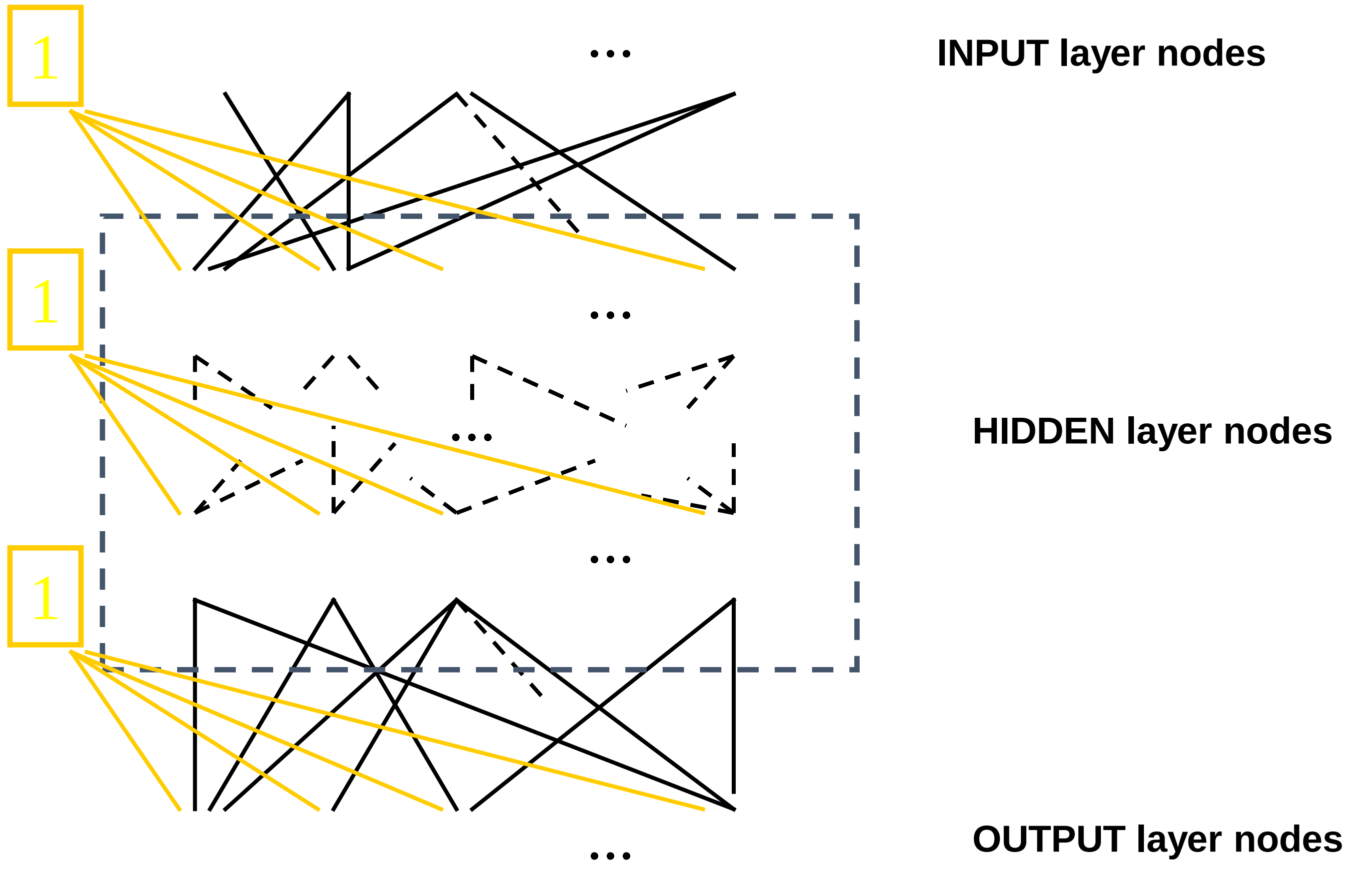
$\dots$ $\dots$

Net

f(*Net*)

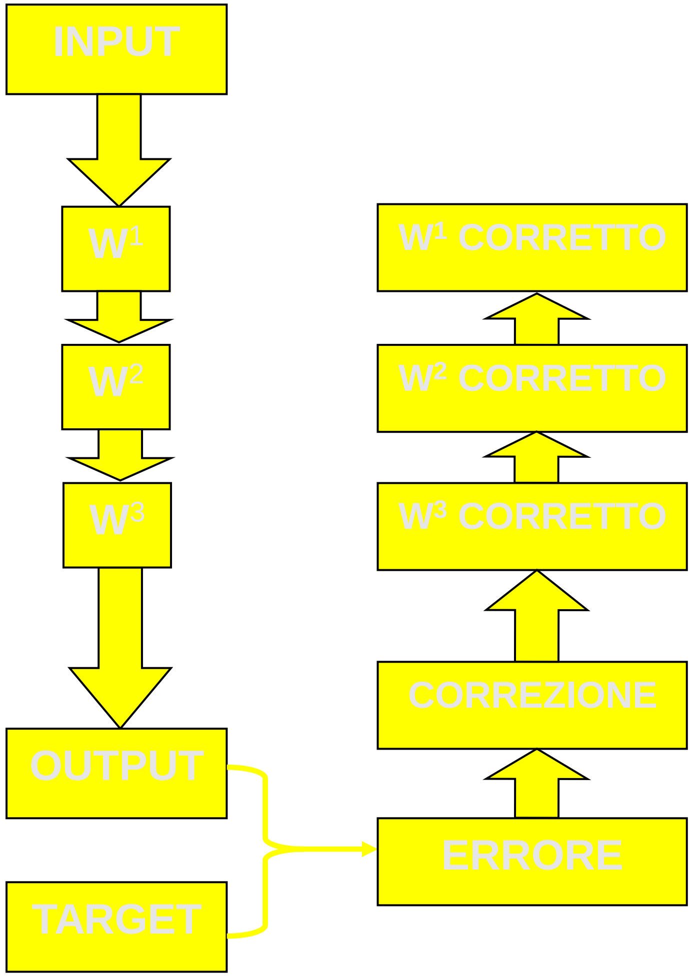
Output

Artificial neural networks

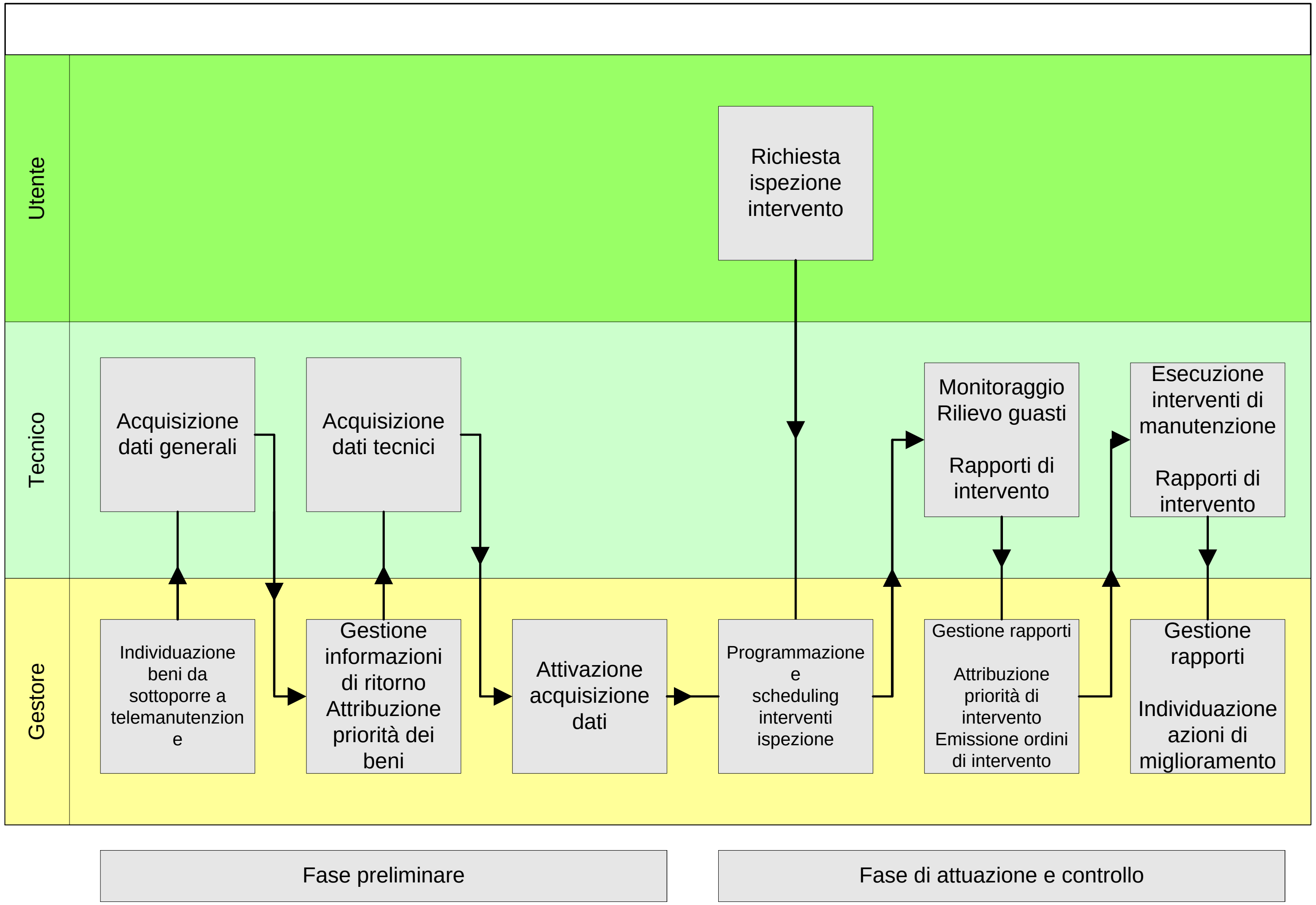


Artificial neural networks

TRAINING OF THE RNA



Tele maintenance - Diagram



Telemaintenance – Application example

Tele maintenance system for technical systems

It allows you to operate and / or receive remote assistance through a monitoring system of technical systems dedicated to the identification of any faults and able to signal in advance the occurrence of a problem.

Telemaintenance – Application example