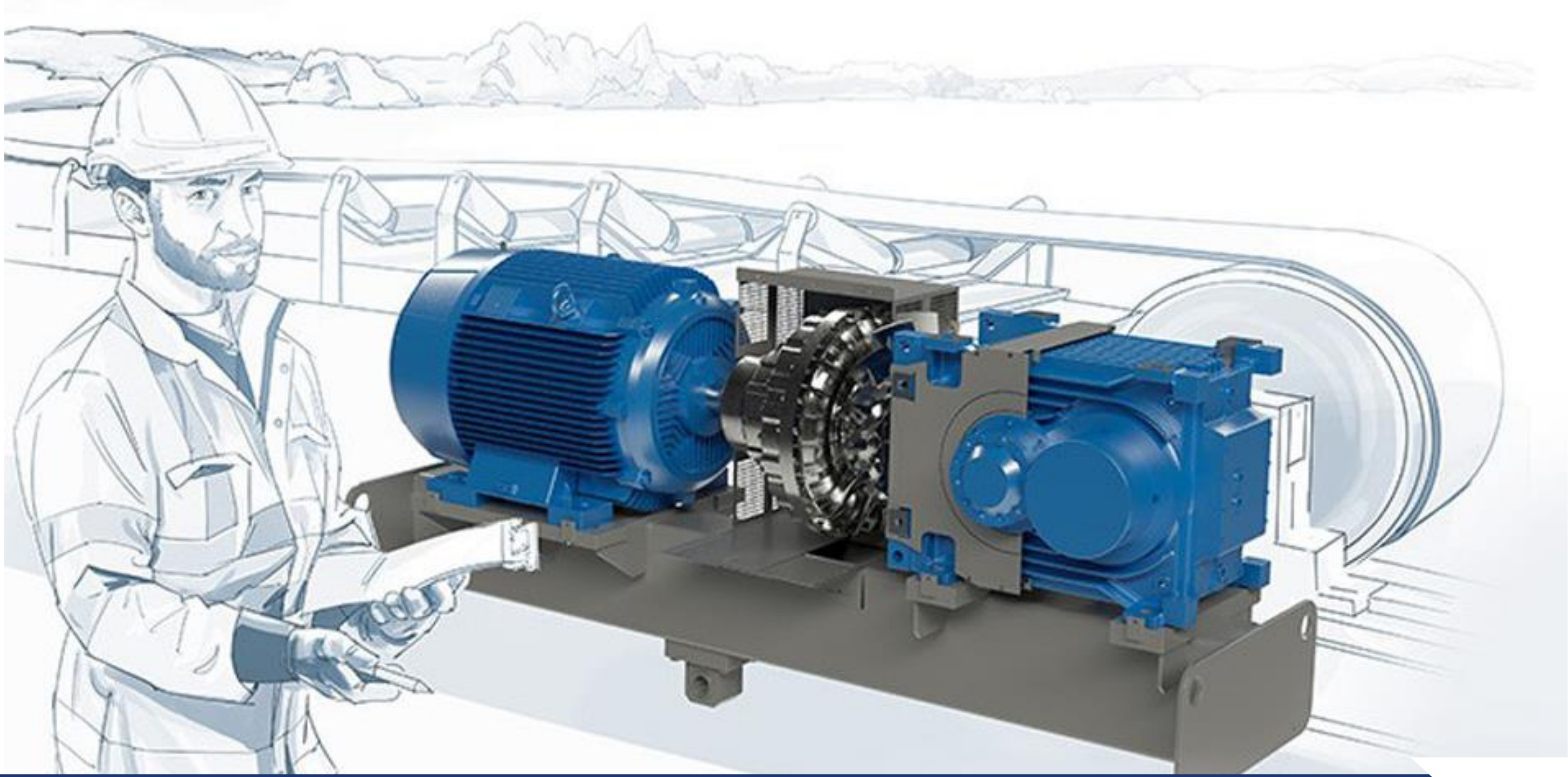


2021

MCTR 701_1
Master Advanced Mechatronics

Lecturers : Luc Marechal, Christine Barthod, Georges Habchi

UNIVERSITÉ SAVOIE MONT BLANC

POLYTECH ANNECY-CHAMBÉRY

SYMME

Mechatronics common framework Lecture 2

Contents

Lecture 2

IMPLEMENTATION OF THE MECHATRONIC SYSTEMS RELIABILITY PREDICTION PROCESS

- Implementation of a specific approach for mechatronic systems
- Application to the two industrial examples previously described

Contents

- Objectives
- Issues
- Preliminary steps to the implementation of the approach
- Mechatronic system
- Bibliographic review (state of the art)

- Proposed approach: 10 steps
- Consolidation of the proposed approach
- Descriptions of the steps’ approach and illustrations

- Conclusions
- Improvement areas

Definitions

Quality = Conformance to specifications or requirements defined by customer at time $t = 0$

Improvement of the quality can be improved by different methods and techniques:

- ISO 9004:2008
- Total Quality Management (TQM)
- Statistical
- Process control
- Six Sigma
- Quality Function Deployment (QFD)
- Quality Circle,
- Taguchi method
- ….

Definitions

Reliability = ability of a system or component to perform its required functions under stated conditions for a specified period of time

Definitions

Maintainability = ability of an item, under stated conditions of use, to be retained in, or restored to, a state in which it can perform its required functions, when maintenance is performed under stated conditions and using prescribed procedures and resources

- To reduce the chance of failures, maintenance can be preventive or predictive:
  - **Corrective Maintenance**: carried out after fault recognition to put an entity into a state in which it can perform a required function.
  - **Preventive Maintenance**: carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of an entity.
  - **Predictive Maintenance**: performed continuously or at intervals governed by observed condition to monitor, diagnose or trend a structure, system or components' condition indicators.

Definitions

Availability = probability that a product or system is in operation at a specified time

The simplest representation of availability (A) is:

$$A = \frac{Uptime\ \ of\ system}{Uptime\ \ of\ system + Downtime\ \ of\ system}$$

Uptime depends on reliability of the system where as downtime depends on maintainability of the system.

Thus availability is function of both reliability and maintainability.

Need for Reliability and Safety Engineering

Failure is inevitable for engineering systems.

Impact of failures :

- minor inconvenience and costs
- personal injury
- significant economic loss
- environmental impact
- deaths

Cause of failure :

- bad engineering design
- faulty manufacturing
- inadequate testing
- human error
- poor maintenance
- lack of protection against excessive stress

Fukushima
Space X
Chernobyl accident
Bhopal gas tragedy
space shuttle Columbia disaster

Need for Reliability and Safety Engineering

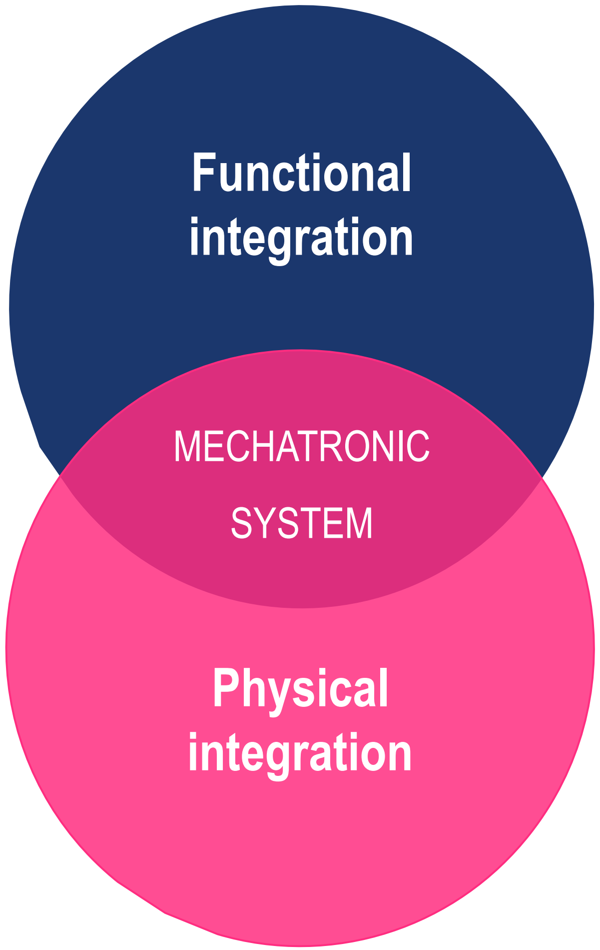
It is essential :
- to understand ‘why’ and ‘how’ failures occur to minimize them
- to know how often such failures may occur

- Reliability deals with the failure concept
- Safety deals with the consequences after the failure

Reliability and safety engineering are improved by the following factors:
- Design evaluation;
- Identification of critical components/events;
- Redundancy requirements;
- Burn-In/Accelerated life tests
- Establishment of preventive maintenance programs;
- Life cycle cost analysis

Issues

Mechatronics → multiple technologies



- Reliability is traditionally studied by technology

  ➔ partitioning and analysis by technical department (electronics, mechanics, software ...)

- Reliability is studied phase by phase_(design, manufacturing,..)

  ➔ *numerous dedicated methods exist with drawbacks, advantages and limitations*

eed for a interdisciplina
and overall approach

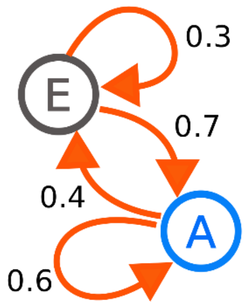
Objectives of reliability prediction of mechatronic systems

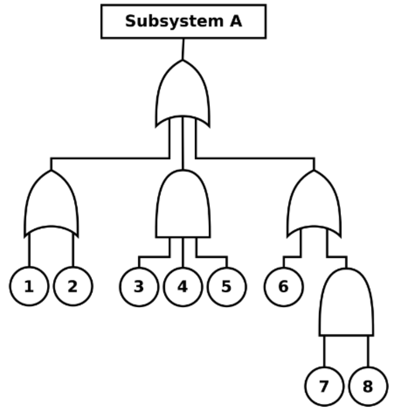
To propose an approach able to estimate the predictive reliability of a mechatronic system during the design phase, that can take into account:

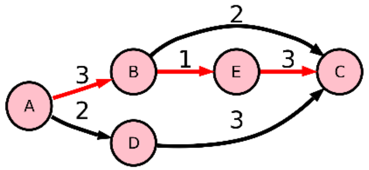
- the intrinsic characteristics of mechatronic systems
- the different components and functions of the system
- the relations between these components and functions
- the mission profile

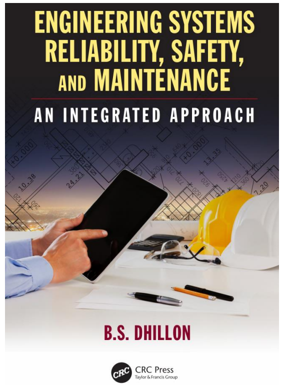
Methods for performing Reliability, Safety, and Maintenance Analysis

- *Markov*
- *FTA (Fault Tree Analysis)*
- *TOR (Technique of Operation Review)*
- ***FMEA (Failure Mode Effect Analysis)***









Engineering Systems Reliability, Safety, and Maintenance
An Integrated Approach, B.S. Dhillon

Bibliographic review / State of the art

Identification and analysis of the state of the art of the different approaches to study the reliability of mechatronic systems

Identification and analysis of the deficiencies and gaps in terms of reliability estimation for mechatronic systems

Keywords	Ziegler 1996	Moncelet 1998	Khalfaoui 2003	Schoenig 2004	Mihalache 2007	Demri 2009
reliability	-	-	-	-	+	+
mechatronic system	-	+	+	+	+	+
modeling	+	+	+	+	+	+
simulation	-	+	-	+	+	+
interdisciplinary dimension	-	-	-	-	-	-
vertical dimension	-	-	-	-	+	-
qualitative study	-	+	+	-	-	+
quantitative study	+	+	-	+	+	+
technological interdependences	-	-	-	-	-	-

- Neither different functioning phasis, nor the mission profile and the influent factors are taken into account
- The physical and functional interactions created between the different technological parts are not studied
- No estimation of the global reliability

An innovative approach designed at SYMME lab - USMB

SYMME

Contents lists available at ScienceDirect

Reliability Engineering and System Safety

journal homepage: www.elsevier.com/locate/ress

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An overall methodology for reliability prediction of mechatronic systems design with industrial application

CrossMark

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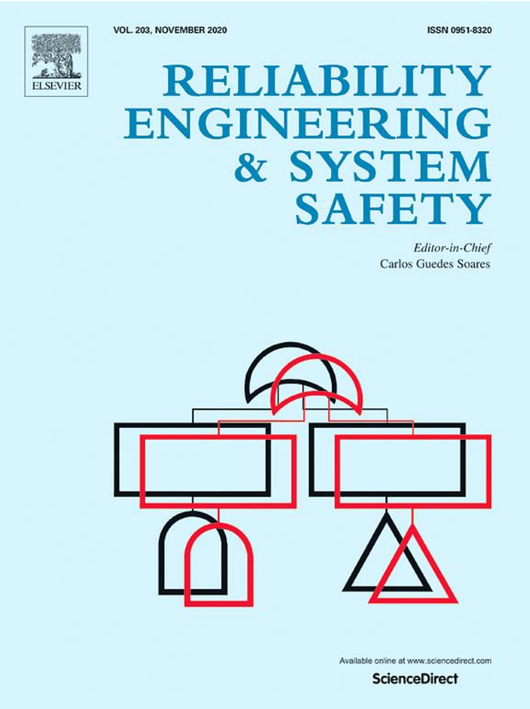
ABSTRACT

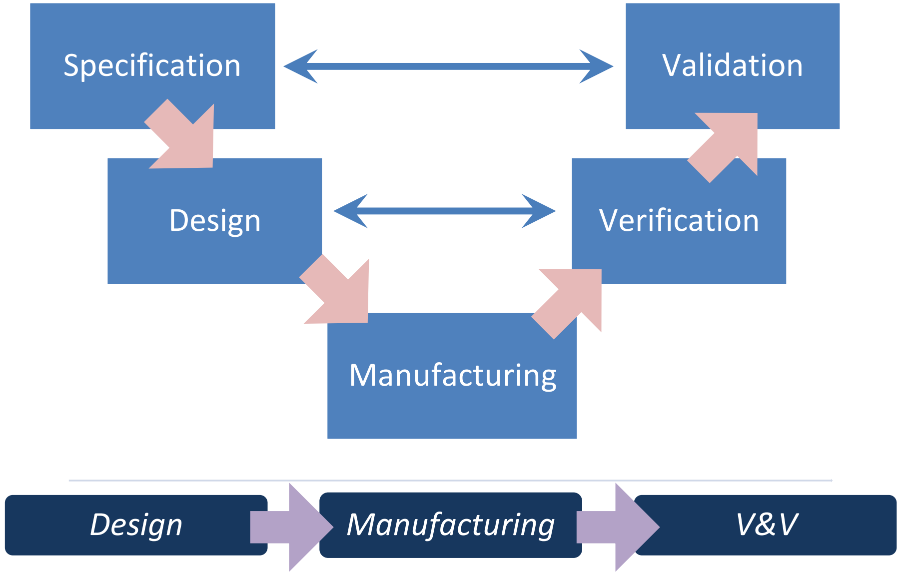
We propose in this paper an overall ten-step methodology dedicated to the analysis and quantification of reliability during the design phase of a mechatronic system, considered as a complex system. The ten steps of the methodology are detailed according to the downward side of the V-development cycle usually used for the design of complex systems. Two main phases of analysis are complementary and cover the ten steps, qualitative and quantitative analysis. The qualitative phase proposes to analyze the functional and dysfunctional behavior of the system and then determine its different failure modes and degradation states, based on external and internal functional analysis, organic and physical implementation, and dependencies between components, with consideration of customer specifications and mission profile. The quantitative phase is used to calculate the reliability of the system and its components, based on the qualitative behavior patterns, and considering data gathering and processing and reliability targets. Systemic approach is used to calculate the reliability of the system taking into account: the different technologies of a mechatronic system (mechanics, electronics, electrical .), dependencies and interactions between components and external influencing factors. To validate the methodology, the ten steps are applied to an industrial system, the smart actuator of Pack'Aero Company.



Proposed approach: initial considerations

Development model

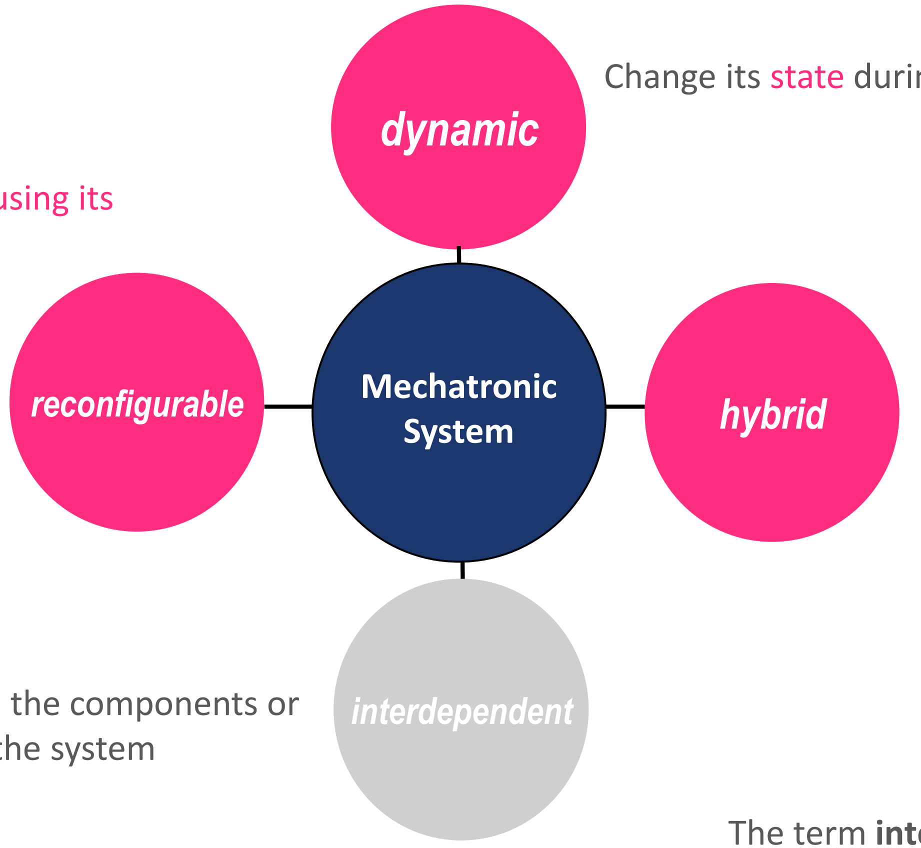
- Based on the V- cycle
- Interdisciplinary and overall approach
- Qualitative and quantitative analysis
- Intrinsic characteristics taken into account at each step
- Under a defined mission profile
- Interactions considered



Proposed approach: initial considerations

Change its state during time

Assume different functions alternatively or a function using its resources in different ways



Continuous phenomenon and discrete events exists

Interactions exits between the components or between the functions of the system

The term **interaction** is defined here as a functional dependence between the components of the system producing a change in the reliability of the system

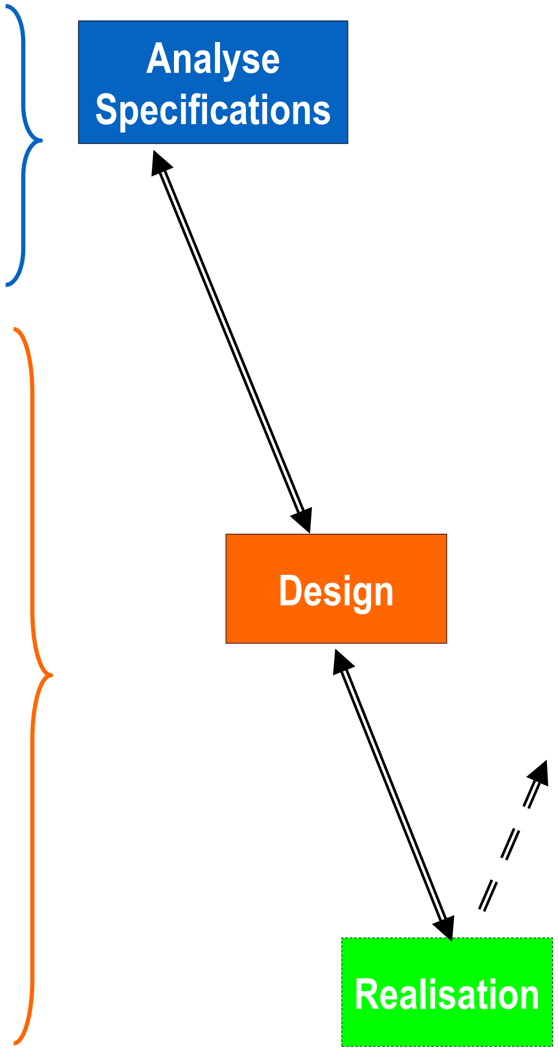
Proposed approach: 10 steps

Qualitative analysis

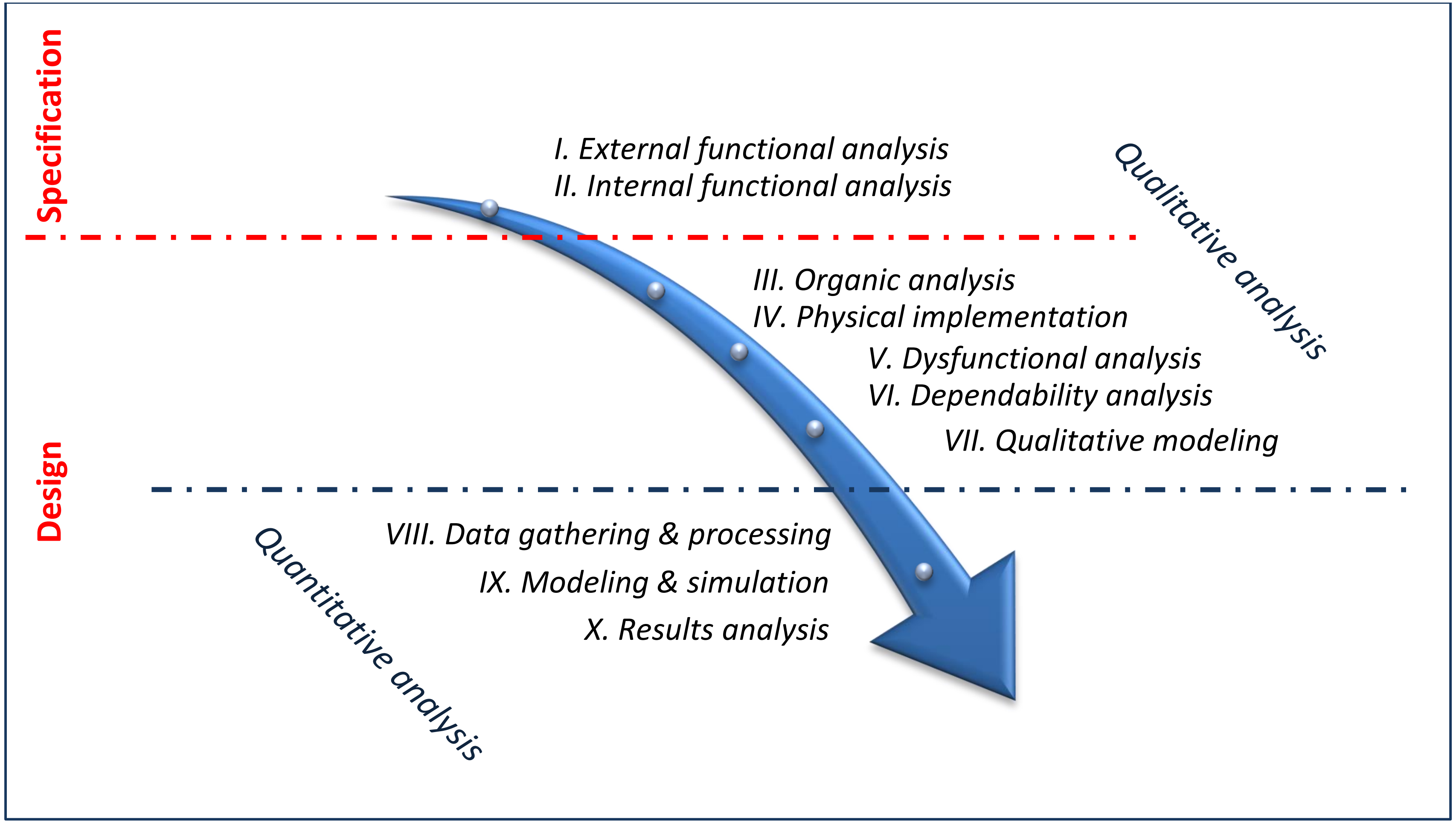
1. External functional analysis (APTE)
2. Internal functional analysis (Bloc Diagrams)
3. Organic analysis (Bloc Diagrams)
4. Analysis of the physical place of the components
5. Dysfunctional analysis (enriched FMEA)
6. Interactions analysis (Interactions matrix)
7. Qualitative modeling (RdP)

Quantitative analysis

8. Data gathering and processing (FIDES, tests, feedback…)
9. Modeling and simulation taking into account the mission profile and the interactions (RdP + Monte-Carlo, DF)
10. Analysis of simulation results



Proposed approach: 10 steps



Preliminary steps to the implementation of the approach

- The estimation of forecast reliability needs to provide the following informations :

  - Complete specifications
  - Reliability objectives
  - **Reliability data** concerning the components of the system and that are not available in database

A strong involvement of the company is needed in the implementation of the approach

Consolidation of the approach

Examples of industrial systems

Choice of 2 examples in order to run through the approach to realise it and consolidate it:

- Simple mechatronic systems
- Principal data available
- Industrial experimented in reliability
- Geographic proximity

PACK'AERO MÉCATRONIQUE

NTN SNR

Example to illustrate

Smart actuator

- **Specifications**

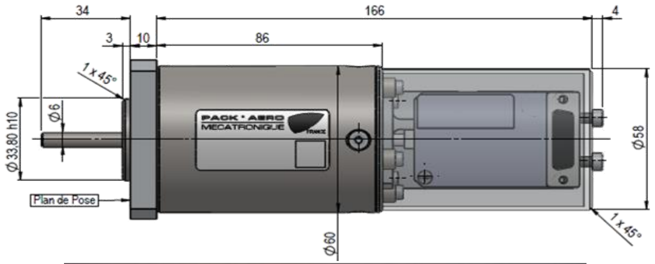
  In addition to be a classical actuator, the smart actuator assume additional functions such as operating, monitoring, communicating, data processing, etc.

  > Transition from passive state to active state

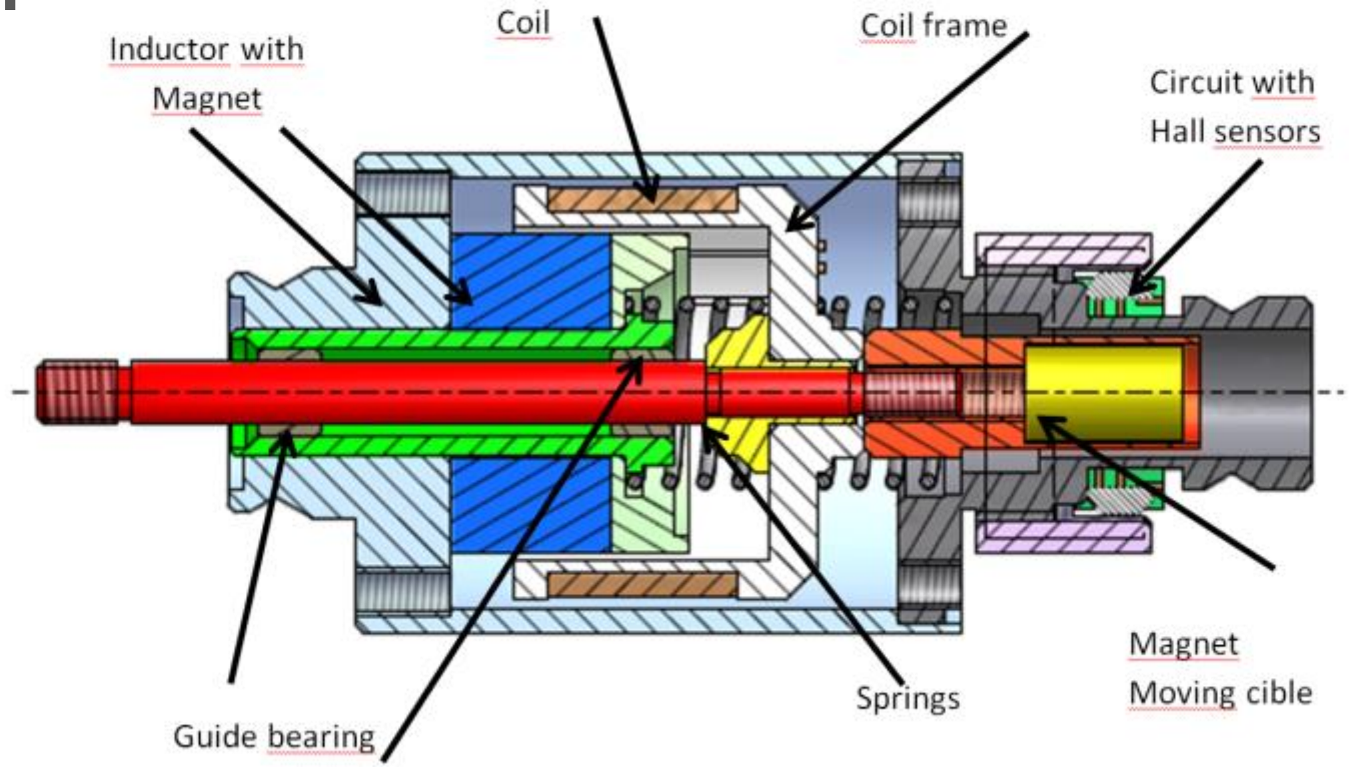
  > Using a linear direct action instead of a linear indirect one

  > Optimisation of the immediate answer according to the needs

  > Integration of electrical locking functions with or without electricity consumption



Overall plan



Physical implementation
of the circuit board

Example to illustrate

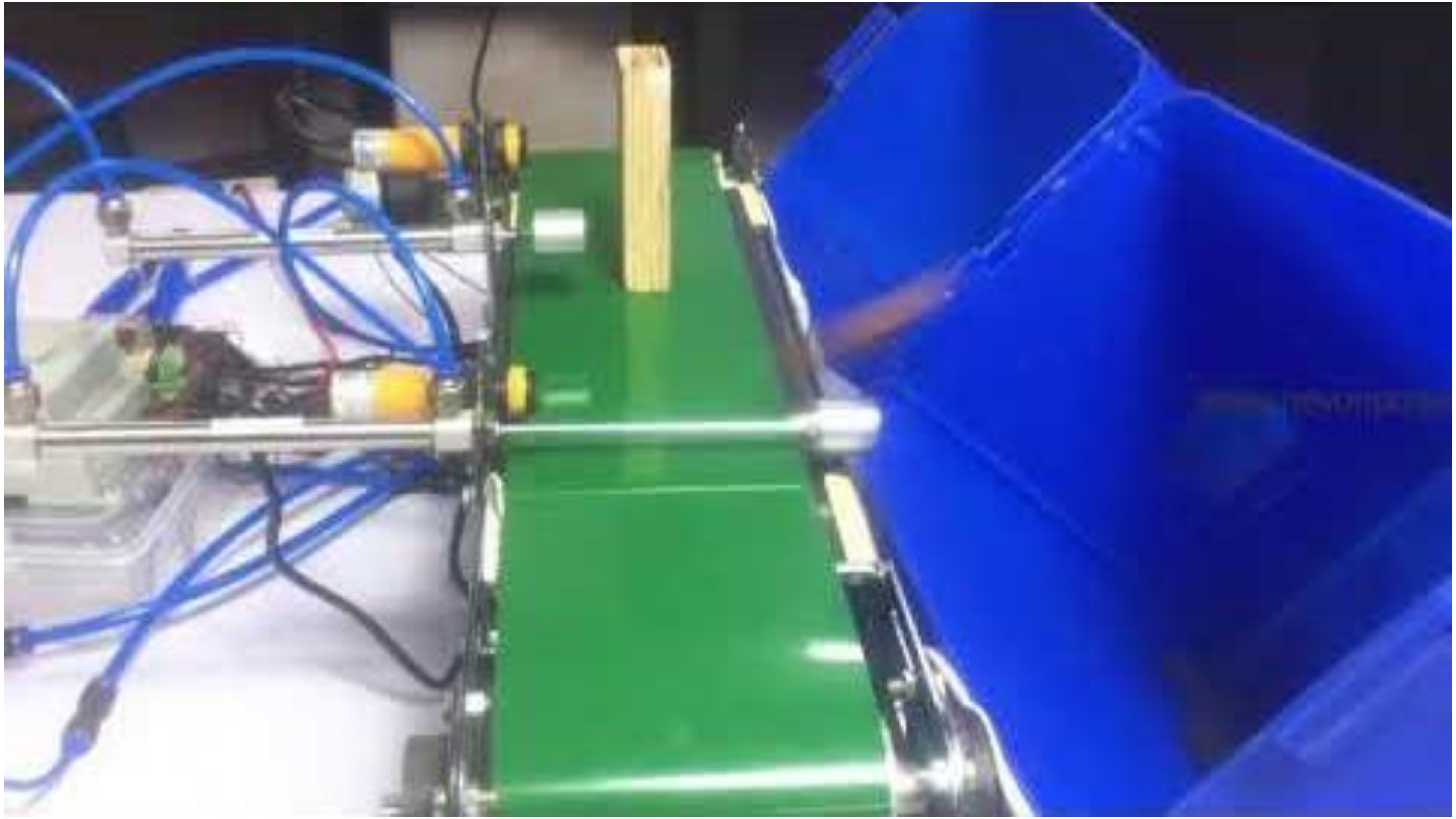
▪ Using context

Continuous sorting line including 200 to 1000 wagons.

- ❑ The wagons carry parts from a station to another of the chain in continuous motion
- ❑ The actuator contributes to the realization of the function of wagons unloading

The finger of the smart actuator is used as a stop to open the shutter and release (let go) the load of wagon without stopping

Example to illustrate



1. External functional analysis

INPUTS

- System requirements specification
- Objectives
- Mission profile

1. External *Functional* Analysis

OUTPUTS

- Main functions and constraints
- Interactions between the system and its environment

Describes:

- The expected funtion for **each phasis of the profile**
- The reactive functions to take into account the environment
- The **contraints** imposed by the users

➔ To write the Functional Specification

Mission profile

Component failure rates are very sensitive to the stresses applied.
Stresses, which can be classified as environmental or self-generated, include:

Temperature Shock Vibration Humidity Ingress of foreign bodies	Environmental
Power dissipation Applied voltage and current Self-generated vibration Wear	Self-generated

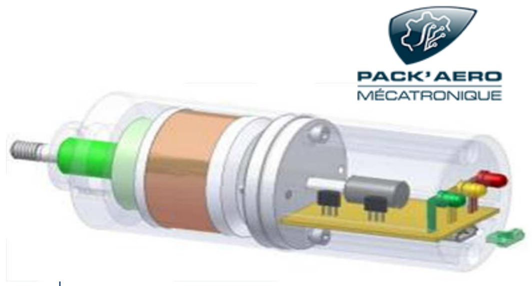
The intended use and environment of a system must be accurately stated in order to realistically measure Reliability.

Mission profiles is an effective tool for that purpose

Mission profile

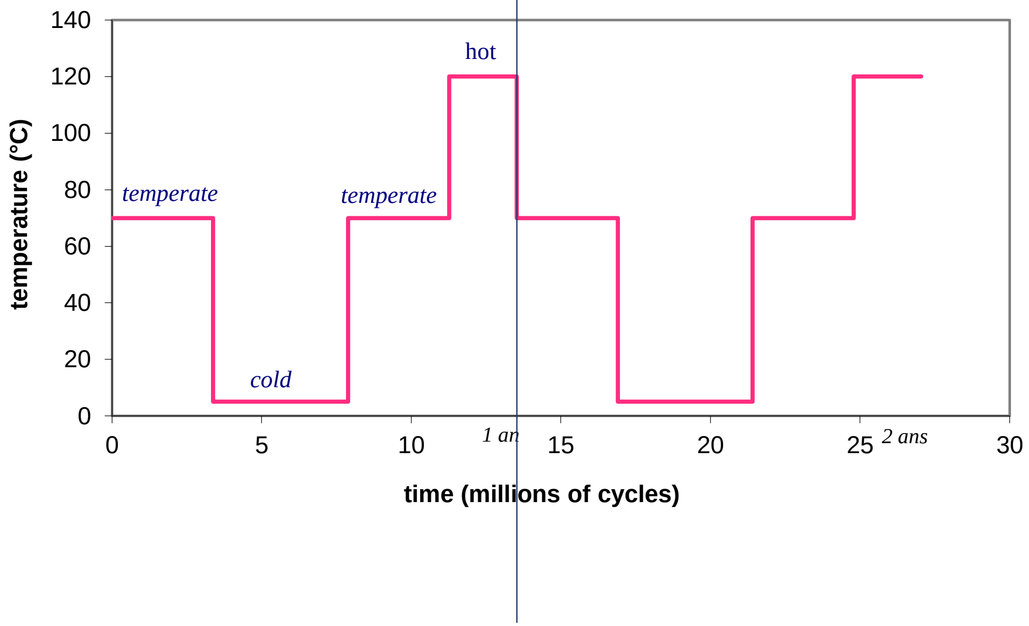
- The mission profile will be taken into account in the estimation of the predictive reliability.

Example of a mission profile for the actuator

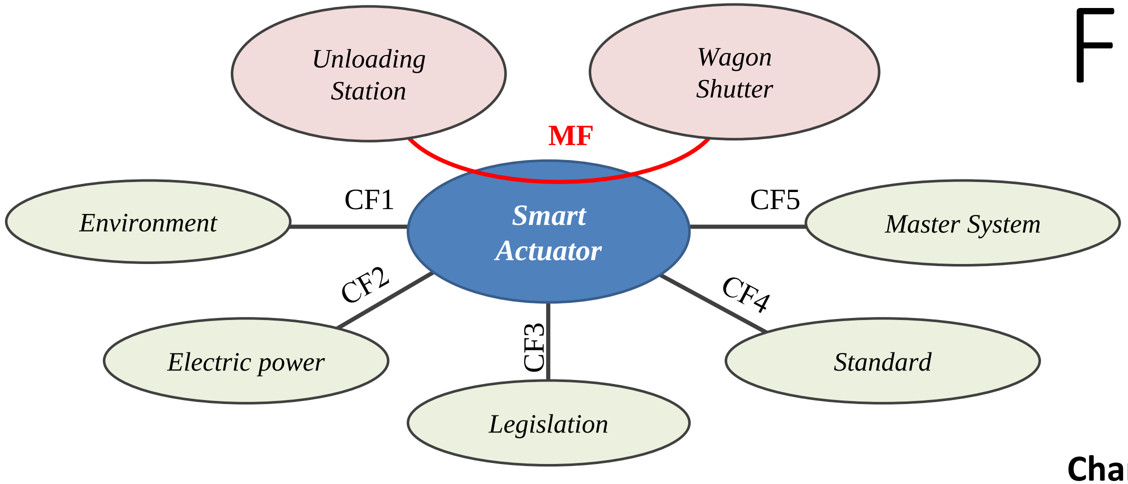


- An influent factor : temperature

- Three different functioning phases: cold, temperate, hot



Functional specification



MF: Allows wagon shutter opening when the wagon arrives at the unloading station,

CF1: Withstands the thermal environment,

CF2: Works with the installed electrical power,

CF3: Meets the requirements of legislation,

CF4: Meets the normative standards requirements,

CF5: Allows the master system to order operating (ON/OFF).

Characteristics of the main function and constraint functions

Function	Criteria/Target	Value/Information
MF	*Average number of opening/closing cycles before the occurrence of a first failure (MTTF)*	*10 million of cycles*
	Desired lifetime	*10 years*
	Operating information	*Intermittent operation* *Electric power: 1 slot ON-OFF/60 ms* *Duration of an opening/closing cycle: 40 ms* *Time between two cycles: 1.67 s* *Operation time 20 h/24, 6 days/7*
CF1	*Temperature and duration of the hot phase* *Temperature and duration of the cold phase* *Temperature and duration of the temperate phase*	*120°C for 2/12 of cycles* *5°C for 4/12 of cycles* *70°C for 2 times 3/12 of cycles*
CF2	*Electric power and voltage*	*10 W and 24 V +/- 5%*
CF3	*Meet the legislation requirements*	*Low Voltage Directive: NSC 20-030* *Directive clean machine (Example: Noise emitted by equipment NFEN 11201)*
CF4	*Meet the normative standard requirements*	*Degree of electrical protection: NFEN60529* *Noise emitted by equipment: NFEN 11201*
CF5	*Working order* *Stop order*	*TOR function (1)* *TOR function (0)*

2. Internal functional analysis

INPUTS

- System requirements specification, objectives, mission profile
- Main functions and constraints,
- Interactions between the system & its environment

⇔

To I/O of the External Functional Analysis

2. Internal Functional Analysis

OUTPUTS

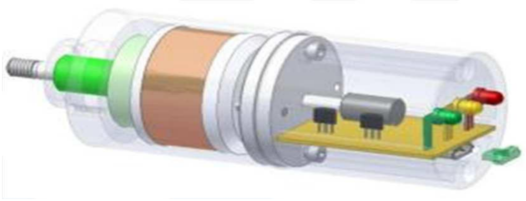
- Functional architecture,
- Choice criterion of the proposed technical solutions
- Description of the internal system & the relationships between internal functions

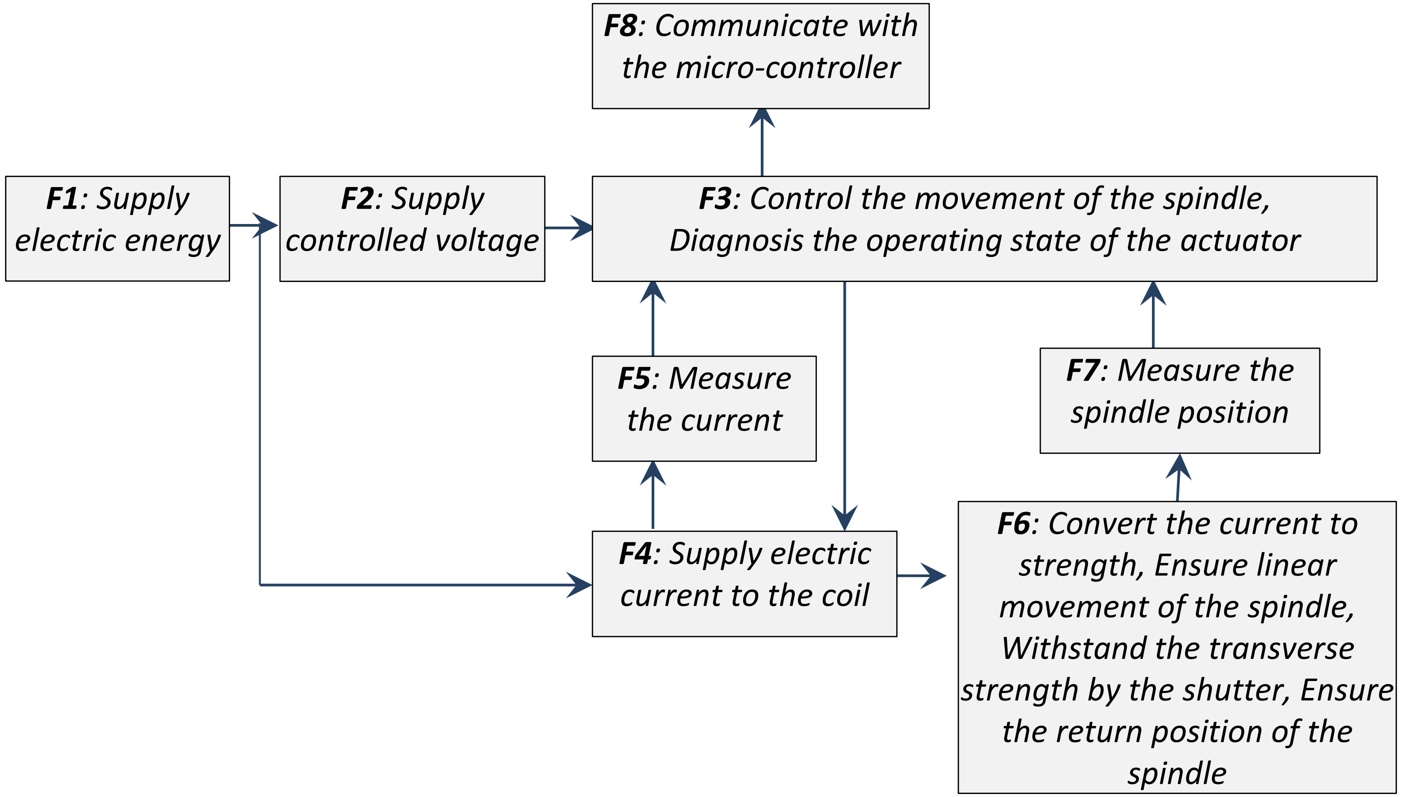
- establishes relationships between the external functional analysis and **possible solutions** to meet the need.
- allows the definition of the functions identified into **internal technical functions**

➔ To make available some elements to compare objectives between different solutions

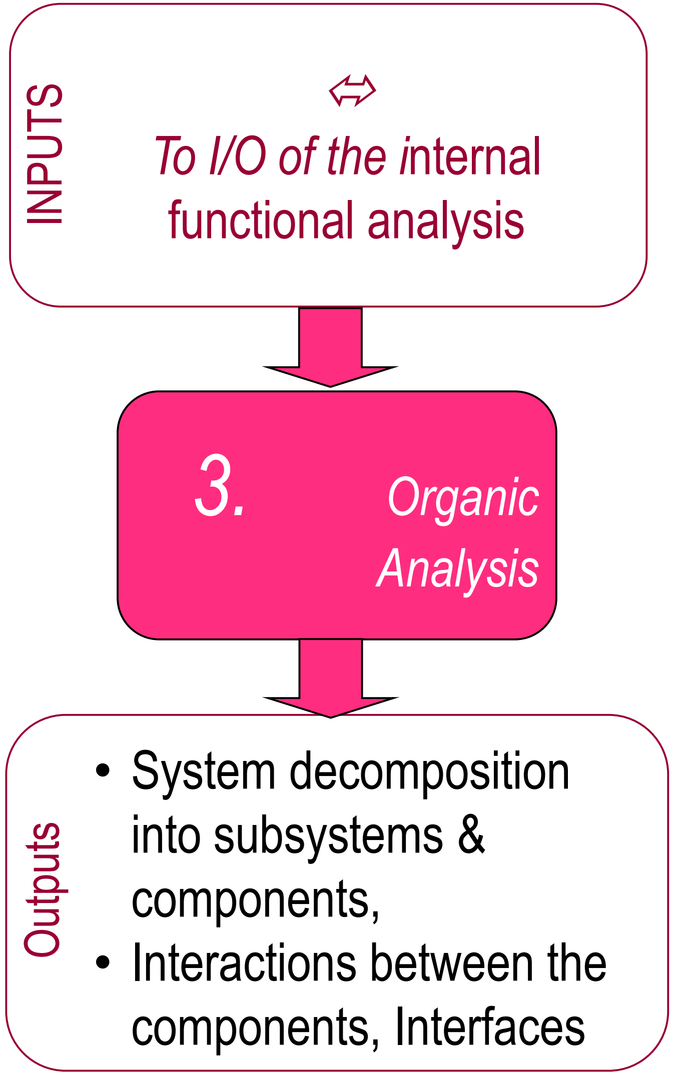
Functional Block Diagram

The Functional Block Diagram is a tool used to map the key internal functions and the relationships between these functions.





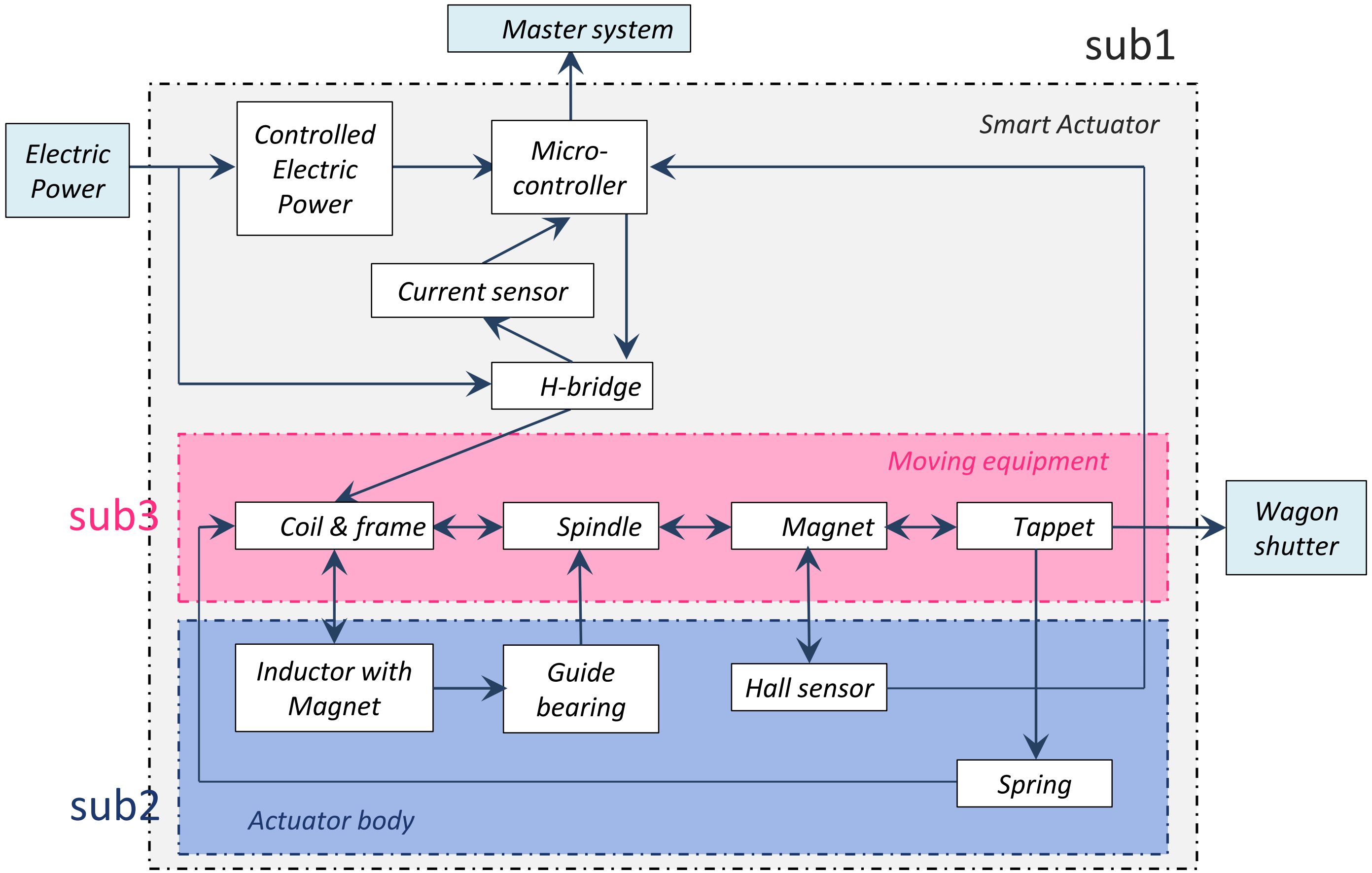
3. Organic Analysis

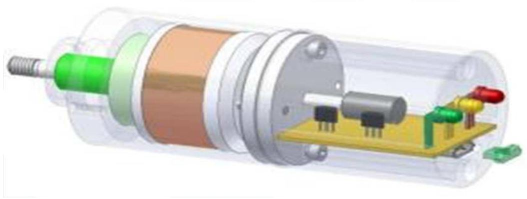


- Defines the **architecture of the system**, the decomposition into **sub-systems and components**

- Identifies the **functional interactions** between the different elements of the system to fit with the expected functions

Organic system architecture





3 sub-systems:

- Sub1= electrodynamic linear actuator with a mobile coil
- Sub2= contactless displacement sensor combining Hall probes and a mobile magnet
- Sub3= conditioning circuit board

4. Physical Implementation

INPUTS
- Sub-systems
- Components
- Interactions
- Interfaces

4. Physical implementation

OUTPUTS
- Overall plan of the system
- Collateral interactions identification

Supplementary step proposed compared to a conventional design approach

- Optimises the **locations** of the parts or organs
- Highlights the **physical proximity** of components

➔ To minimise the collateral interactions' effects on the reliability of the system

5. Dysfonctional Analysis

INPUTS

- Specifications
- Failure history
- System internal functions
- Interactions between the system and its environment
- System architecture
- Physical implementation
- Preliminary Analyze of Risk

5. Dysfunctional *analysis*

OUTPUTS

- Identification of potential damage, their causes & their effects on the system
- Action plan

- Identifies failure modes and rank them according to their effects on the product performance:
  > **Intrinsic** failures
  > **Functional** failures identified thanks to the organic architecture
  > **Collateral** failure **issued from the physical implementation analysis**
- FMEA (Failure Modes and Effects Analysis) ➔ inductive approach to analyze the failure modes and their effects to order them (according to their criticity) to master them.

FMEA (Failure Mode Effect Analysis)

- FMEA is a widely used method for analyzing the reliability of engineering systems

- It involves studying a circuit or mechanical assembly to decide how its component parts contribute to the overall failure mode in question.

- The method consists of assessing the effect of each component part failing in each possible mode.

- Step 1: Define system boundaries and its associated requirements.
- Step 2: List system subsystems and components.
- Step 3: List each component’s failure modes, the description, and the identification.
- Step 4: Assign failure occurrence probability/rate to each component failure mode.
- Step 5: List each failure mode effect/effects on subsystem(s), system, and plant.
- Step 6: Enter necessary remarks for each failure mode.
- Step 7: Review each critical failure mode and take necessary actions.

FMEA (Failure Mode Effect Analysis)

- **Description**
  - describes inherent causes of **events** that lead to system failure,
  - determines their **consequences**
  - formulates methods to minimize their occurrence or recurrence.
  - allows identifying the **critical** elements of security and dormant faults.
- **Advantages**
  - **Simple** approach
  - Large application domains: design and exploitation
  - Analysis table giving a good **traceability** and **decision** support
- **Drawbacks / limitations**
  - Considered only one failure at a time
  - Limited insight into the functional relationships between components,
  - Time element in system operation cannot be represented.
  - Limited insight into probabilistic system behavior,
  - Better-adapted for mechanical or analog systems than digital ones

FMEA (Failure Mode Effect Analysis)

Enriched method

Classification of the failures according the damage's origin (intrinsic, collateral, and functional) and giving:

- its nature (first or second or by command)
- its event speed (sudden or progressive)
- its amplitude (partial or complete)

Sub-system	component	Function	Failure mode	Cause	Effects	Damage's origin	Classification : nature / event speed / amplitude
mobile	Coil + frame	F6	- Swelling of the cuivre wire [8]. - Swelling of the frame - Breakdown of the material - Breakdown of the wire [8] - Wrong value of the current on the coil - Wrong position of the frame	Thermal heating, vibration, impact	No opening of the shutter	Collateral	Second, progressive, partial
				Excessive pressure or excessive translation speed	No opening of the shutter	Collateral	Second, progressive, partial
				Material fatigue [8]	No opening of the shutter	Intrinsic	First, progressive, complete
				Damage of inductor with magnet	No opening of the shutter	Fonctional (*Inductor → Coil)*	First, sudden, complete
				Damage of H Bridge	No opening of the shutter	Fonctional (H-Bridge → *Coil)*	First, sudden, complete
				Decentering of the rod	No opening of the shutter	Fonctional (*Rod → coil frame)*	First, sudden, complete

6. Dependency analysis of interactions

IMPUTS

- FMEA ‘s outputs

6. *Dependancy* analysis of *interactions*

OUTPUTS

- Interactions matrix
- Interactions effects
- laws of variation of the reliability parameters
- Interactions to be taken into account in the model

Additional analysis compared to a conventional design approach

- Identifies interactions defined and classified in the **enriched FMEA** (a criticality analysis will be necessary).
- Allows to make the **choice of the interactions to be considered** in modeling the system in terms of reliability.

Interactions matrix

Acts on		Subsystem 1			Subsystem 2		
		Comp 1	*Comp 2*	*Comp 3*	*Comp i*	*Comp k*	*Comp n*
Subsystem 1	*Comp 1*		***UF***		***BF***		
	Comp 2						
	Comp 3						
Subsystem 2	*Comp i*					***UC***	
	Comp k		***BC***		***UF***		
	Comp n						

UF for unidirectional functional interaction
BF for bidirectional functional interaction
UC for unidirectional collateral interaction
BC for bidirectional collateral interaction

- Power supply acts on controlled power and on H-bridge,
- Controlled power acts on micro-controller,
- H-bridge acts on current sensor and on coil,
- Micro-controller acts on H-bridge and on master system,
- Current sensor acts on micro-controller,
- Coil acts on shutter,
- Magnet acts on tappet and on Hall sensor,
- Coil acts on inductor & magnet / inductor & magnet acts on coil,
- Magnet acts on shutter / Shutter acts on magnet.

7. Qualitative Modeling

ENTREES

- System internal functions
- Interactions between the system and its environment
- System architecture
- FMEA

7. Qualitative Modeling

SORTIES

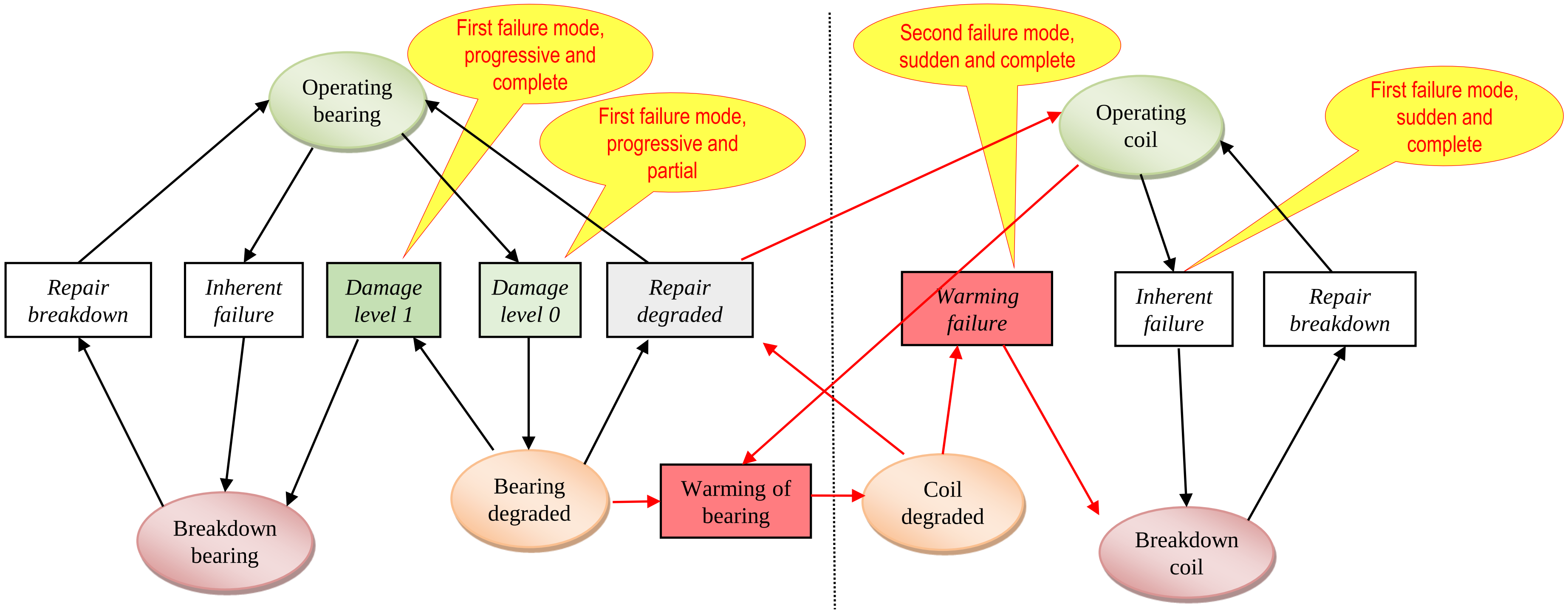
- Functional & dysfunctional models of components, sub-systems and system

Models the functional and dysfunctional behavior of the system and its components, taking into account the interactions

- **States**: idle, operating, breakdown (whatever the mission profile phase), repair and degraded,
- **Transitions between states**: failure modes, events, repair modes

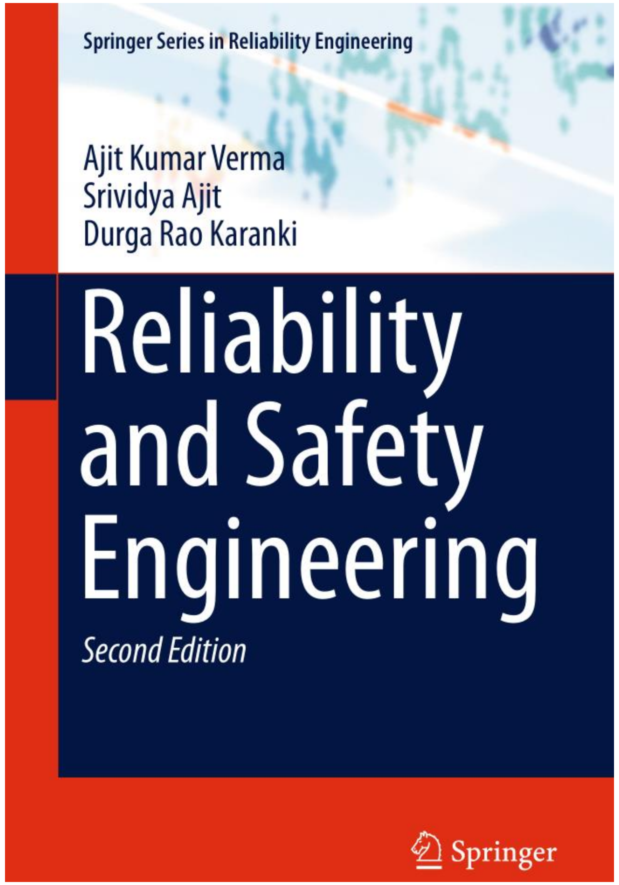
Qualitative modeling

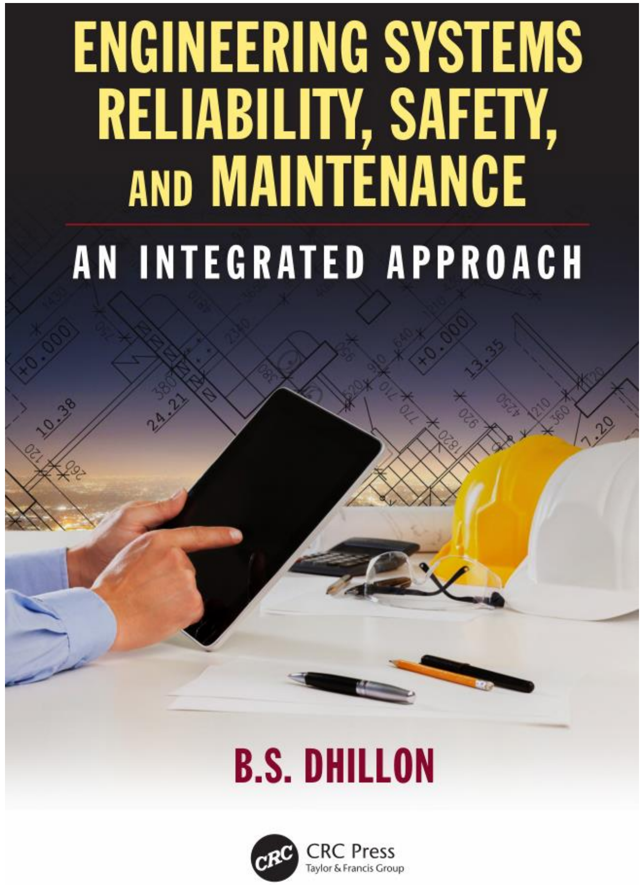
- Modeling of both componants: guide bearing / coil
  - Bearing wear
  - Collateral interaction linked to the physical implementation guide bearing / coil



- Interactions modeled by implemented new states and modes:
  - > *5 states for each component:* idle, operating, breakdown, repair and degraded
  - > *3 failure modes for the bearing,* 2 failure modes for *the coil*
  - > *2 repair modes for the bearing, 1* repair mode for *the coil*

Relevant books





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