Evaluation of Human Factor within System Reliability

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- The agenda of this speech will be as follow:
  - HRA
  - CREAM
  - The Case Study
  - The Assessment Methodology
  - Simulation Results
  - Conclusion and Development

HRA – Human Reliability Analysis

In high risk industry management, an important aspect is represented by human error, which can lead to accidents with adverse consequences.

The area associated with identifying, analysing, and managing human error is generally known as Human Reliability Analysis - HRA.

HRA is developed in two directions:

The First Generation Methodologies

- very close to Probabilistic Safety Assessment
- the research is directed to define human error and to quantify human error probability without emphasizing its causes.

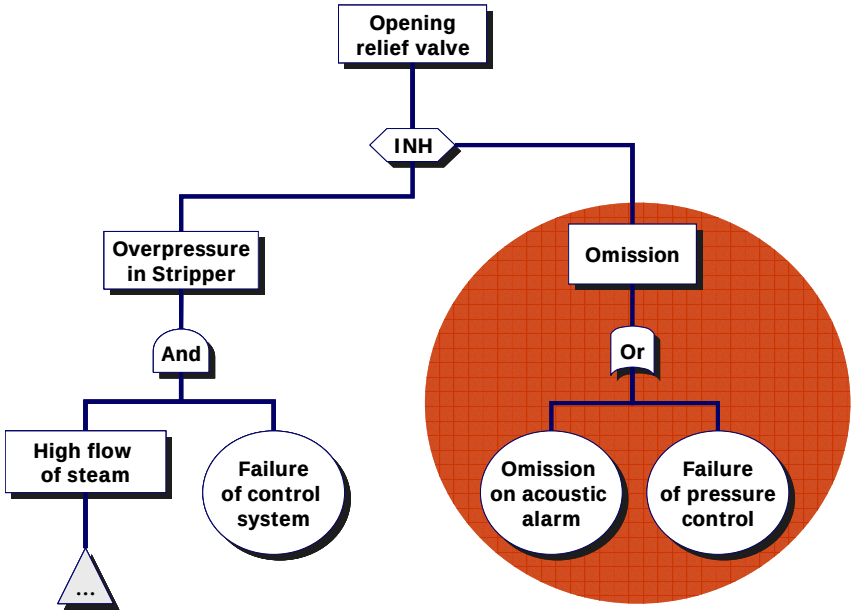
The Second Generation Methodologies

- unties itself from quantitative approach
- looks for a complex system quality description, developing man–machine interface models and cognitive models.

HRA: I and II generation methodologies

I Generation

- quantifying error probability
- defining human error

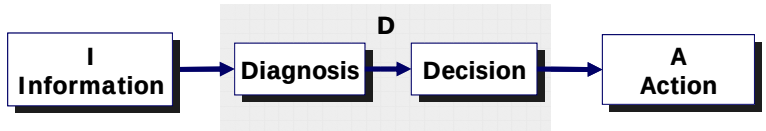


It didn't consider hidden failure

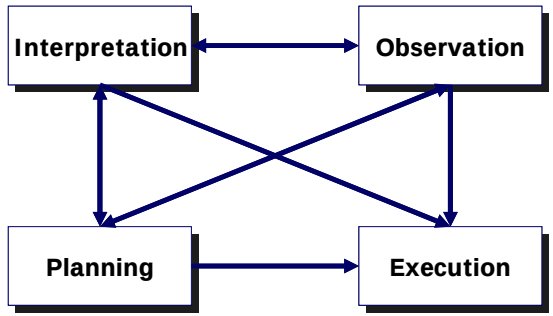
II Generation

- man–machine interface models
- cognitive models

sequential cognitive model

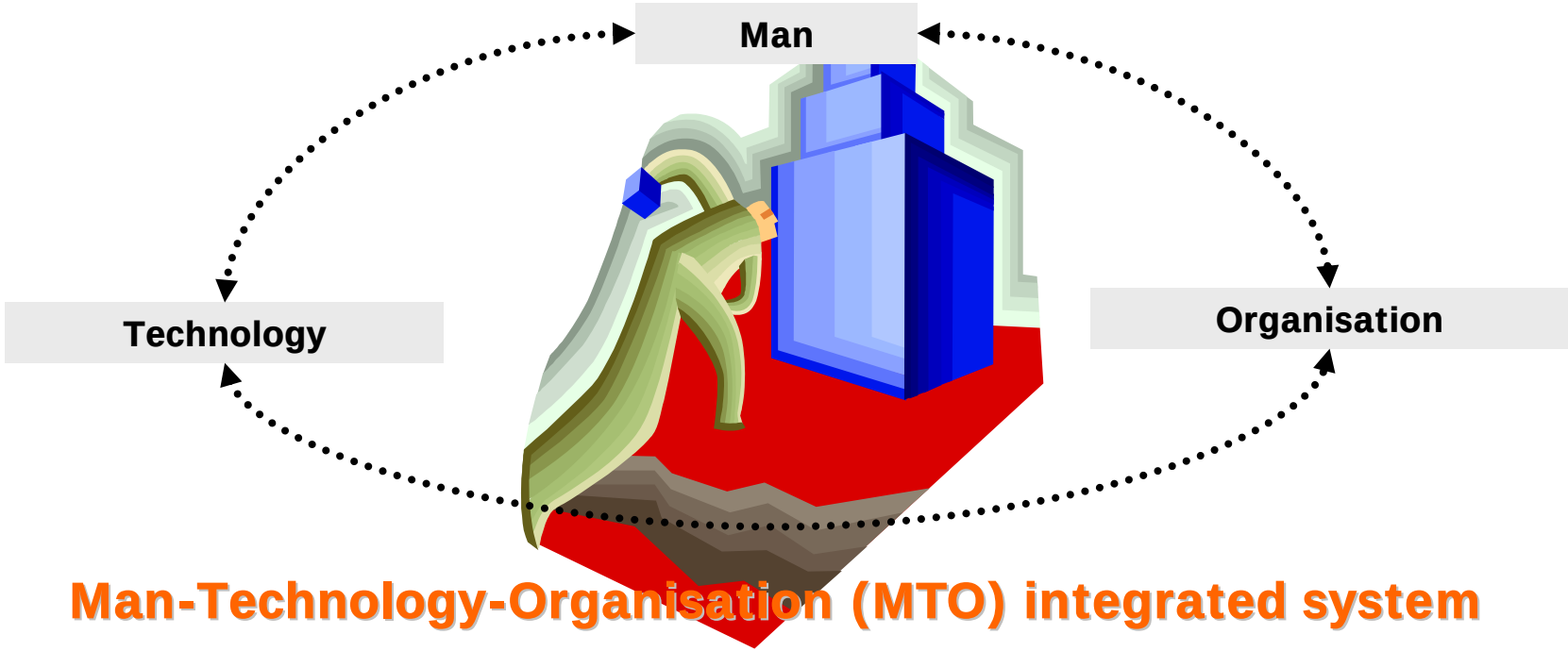


cyclical cognitive model



CREAM: Integrated system

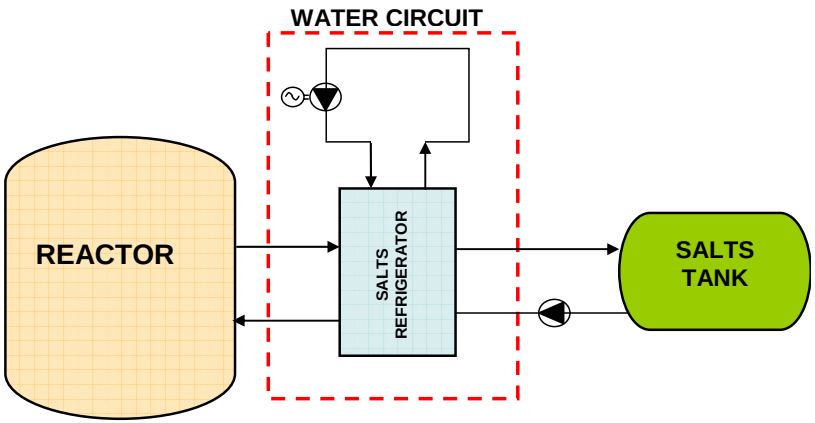
In human reliability analysis, the domain is defined by Cognitive Reliability and Error Analysis Method (CREAM)



Man-Technology-Organisation (MTO) integrated system

→ team (**Man**), which works to get the same mission
→ acting on the mechanics of the process (**Technology**)
→ among the system organization and management (**Organisation**).

The Case Study: Reactor Cooling System



- chemical production plant;
- phtalic-anhydride productin cycle;
- cooling system failure could provoke a relevant incedent;

Reactor ⇒ Salts Circuit ⇒ Water Circuit

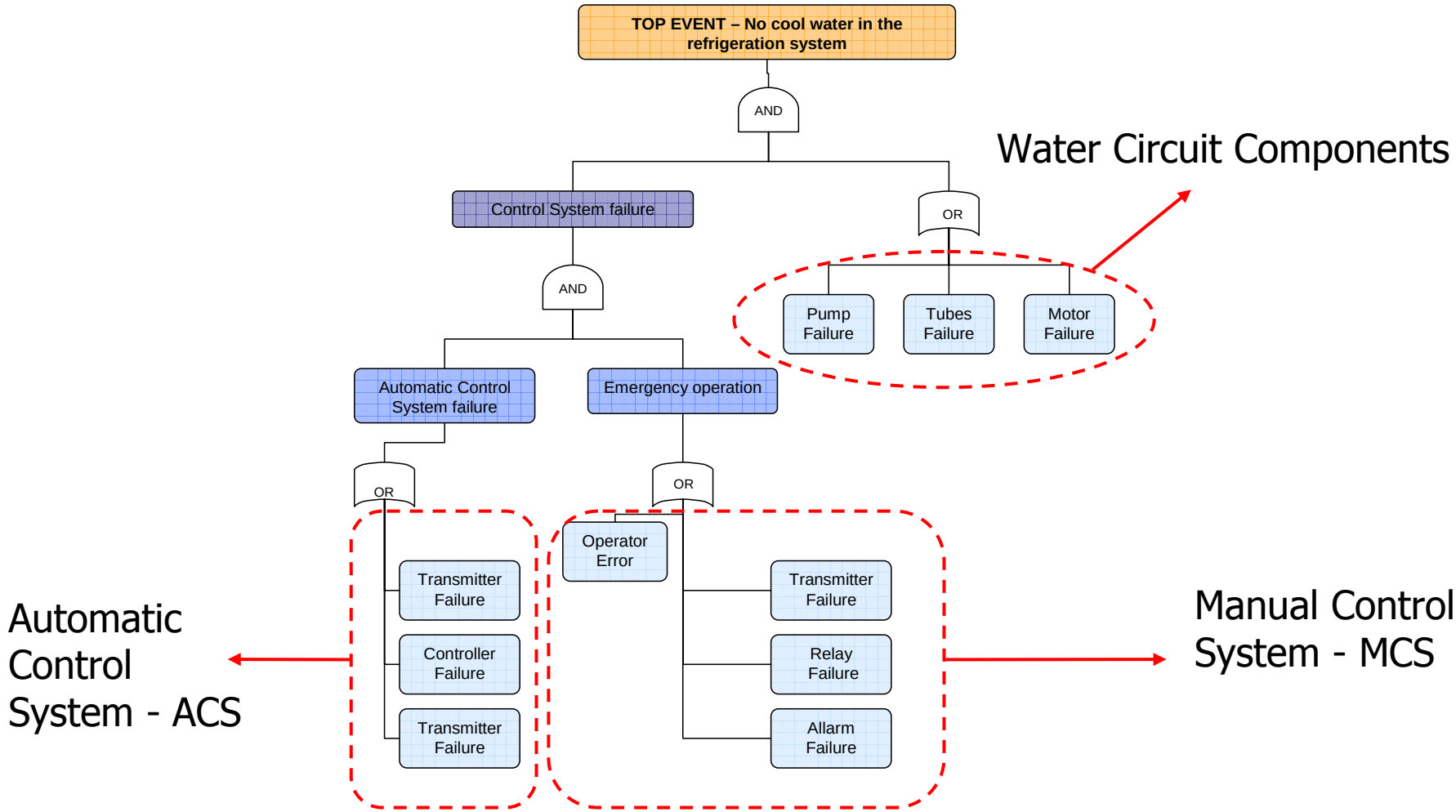
Process variable: TEMPERATURE

Product Quality

Diagnostic parameter for a failure event

Control Room with a Diagnostic panel

The Case Study: Fault Tree Analysis of Reactor Cooling System

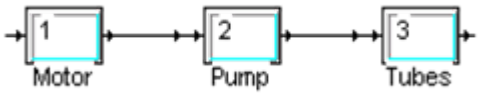


The Assessment Methodology: Simulation

Simulator software: SPAR (produced by ClockWork Group):
- Represent a very large number of work timetables;
- Manage numeric values uncertainty;
- Modify system logics during the simulation runs.

The system implementation in the process simulator required the following steps:
1. Reliability Block Diagram (RBD) construction;
2. Definition by reliability values and data (MTBF, MTTR, maintenance policies man maintenance inspections);
3. Creation of management logics by some code lines with the Bubble Maker tool.

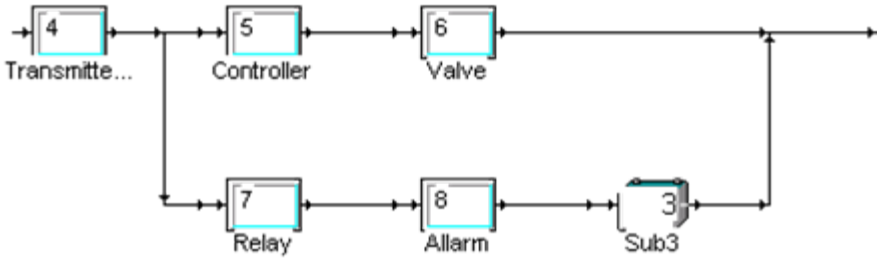
RBD – Reliability Block Diagram of the mechanical components



ACS – Automatic Control System: 1° Configuration

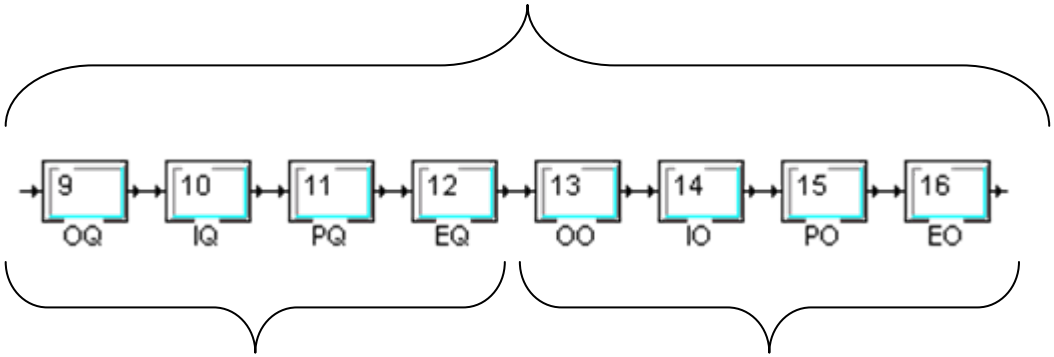
- Checked Parameter: Temperature

ACMS – Automatic and Manual Control System: 2° Configuration



Parallel control system:

- Transmitter is the main criticity



Cognitive Functions

- Observation
- Interpretation
- Planning
- Excution

Team work: Control Panel Operator + Field Operator

phone call

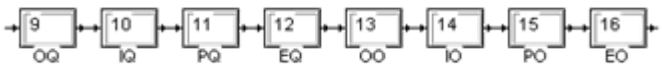
Manual procedure: First Step + Second Step

Operator shift works:

- 8 hours each team
- 3 teams

The Assessment Methodology: Human Factor Introduction

- Human factor influence is introduced by procedures that represent the sequence of operations that human operators have to do.
- In every task it is possible to recognize cognitive activities and basic cognitive functions.
- Considering that human operators should complete all the cognitive functions requested from their tasks, the overall cognitive functions would be represented by a serial system.



The series model doesn't mean that the sequence of the cognitive function is the one of the representation, but that **every function** is **necessary** for the fulfillment of the mission

Each block is implemented by its theoretical cognitive function failure rate and it comes from:

$$\lambda_{Tcf_z} = n \cdot i_v \cdot \sum_{j=1}^{l} \lambda_{j_z}$$

- n is the cognitive function occurrence in a single procedure
- i_v is the average procedure evaluation index for each cognitive function

iv

- $\lambda_{j\,z}$ are the nominal values of cognitive function failure modes for each one of the z (four) cognitive functions.

CREAM

The Assessment Methodology: HTA & CTA

HTA – Hierarchical Task Analysis: Procedures Analysis

Cognitive Demand Profile:

- Procedure is broken down in tasks
- For each task have been identified cognitive actions
- For each cognitive action there is a cognitive function assessment by numerical value
- Overall evaluation index is assigned to each cognitive function

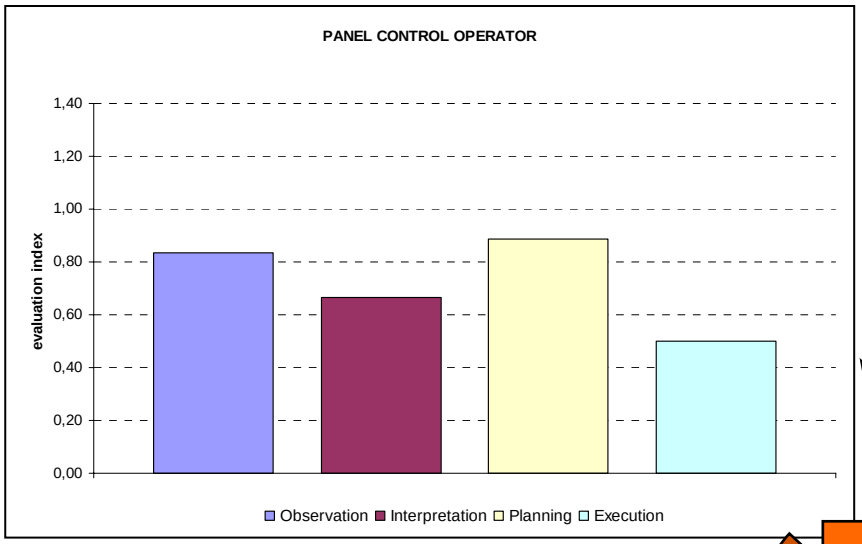
STEP N°	TASK	Cognitive action	PANEL CONTROL OPERATOR												evaluation indexes			
			cognitive function															
			O			I			P			E			f_O	f_I	f_P	f_E
			p	r	i	c	v	d	d	e	c	v	s	f				
1	System monitoring	monitoring	3	3	3	3	3	3							1,00	1,00		
2,1	Alarm type definition	identification				0	3	3								0,67		
2,2		diagnosis				3	0	3	3	3	3					0,67	1,00	
3,1	Action plan definition	evaluation				3	0	3	3	0	3					0,67	0,67	
3,2		planning							3	3	3						1,00	
4,1	Calling operator in field	identification				3	0	3								0,67		
4,2		communication				3	0	3				3	0	0		0,67		0,50
4,3		verification	0	3	3	0	3	0							0,67	0,33		
5																		
6,1																		
6,2																		
6,3																		
COGNITIVE DEMAND PROFILE															0,83	0,67	0,89	0,50
COGNITIVE FUNCTIONS OCCURRENCE			2	2	2	7	7	7	3	3	3	1	1	1				
			15,4%			53,8%			23,1%			7,7%						

iv

CTA – Cognitive Task analysis

The Assessment Methodology: Cognitive Profile

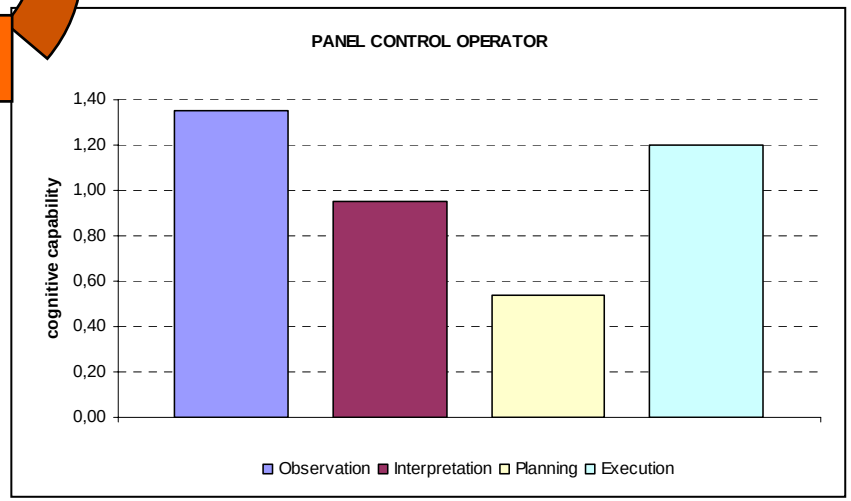
Demand Cognitive Profile



Whenever the operator's skills are lower than the demand, this model proposes an increase of each one of the λrcf_z, proportionally to the gap between the required cognitive profile and the available one.

GAP

Available Cognitive Profile

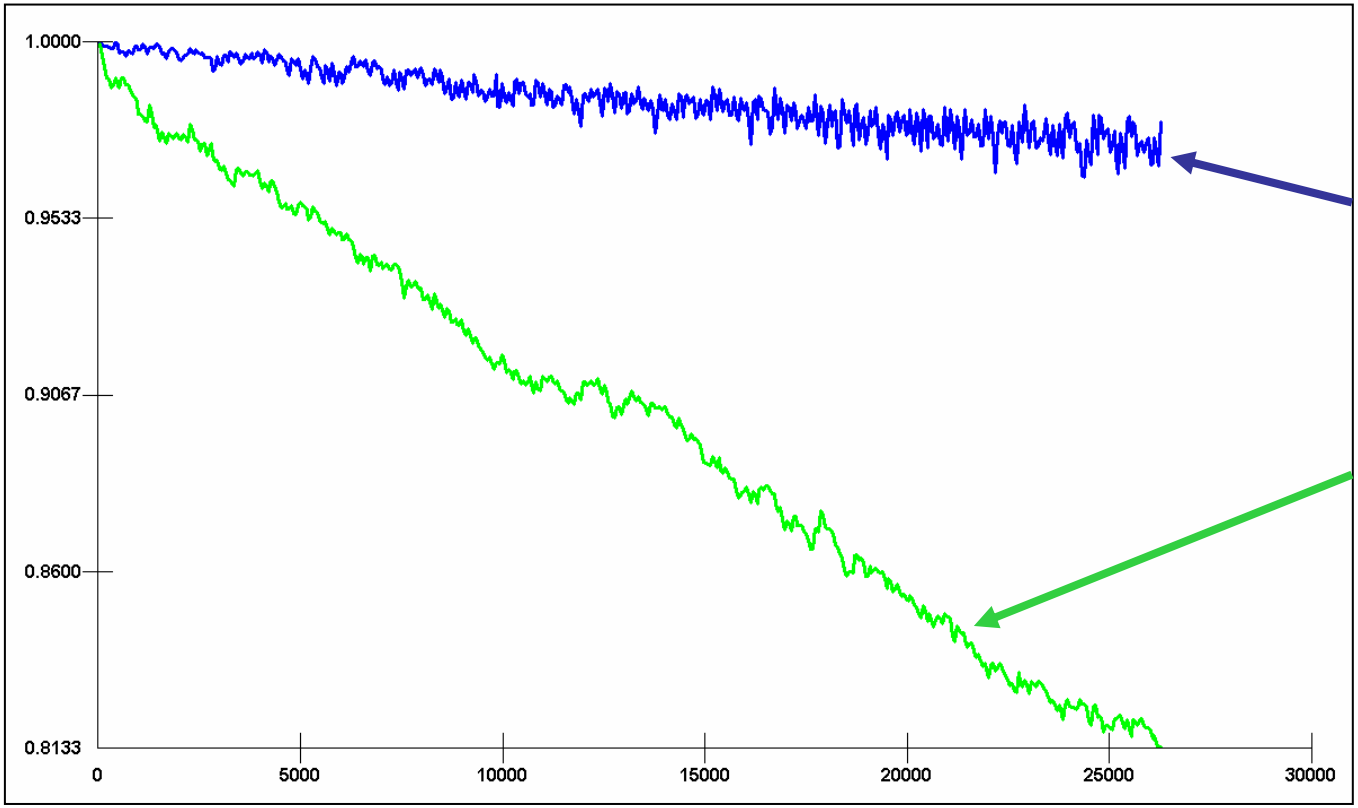


$$\lambda_{Rcf\,z} = \max\left\{\lambda_{Tcf\,z}(1+\alpha_z);\lambda_{Tcf\,z}\right\}$$

$$\alpha_z = \frac{Freq_z - Faval_z}{Freq_z}$$

with $z = 1$ to 4 (cognitive functions)

Simulation Results: Correct working of the Control System



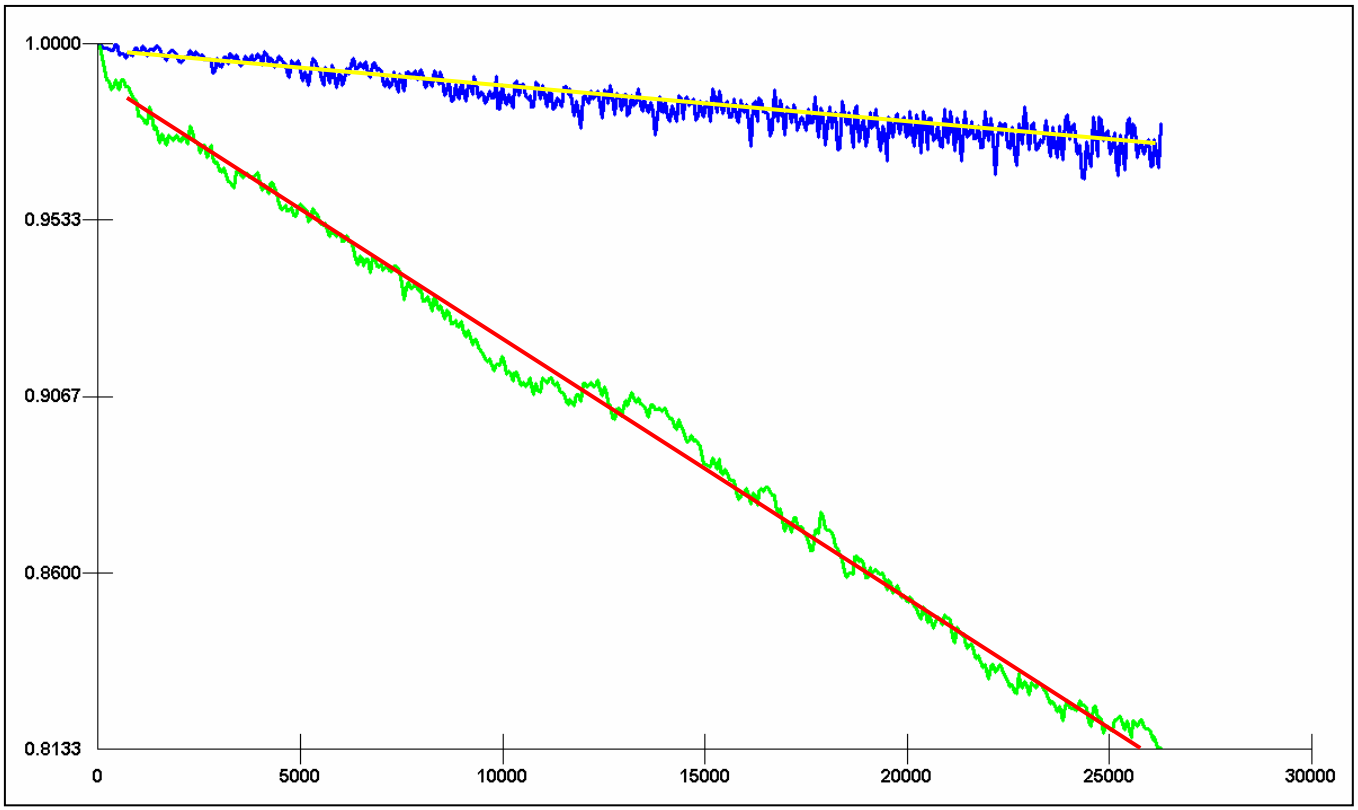
- x, operating hours
- y, event probability
- blue line is the AMCS – Automatic and Manual Control System performance
- green line is the ACS – Automatic Control System perfomace

- Operating average probability

  0.89 ⟹ 0.98

- Δp(e)MAX= 0.97 - 0.81= 0.0.16

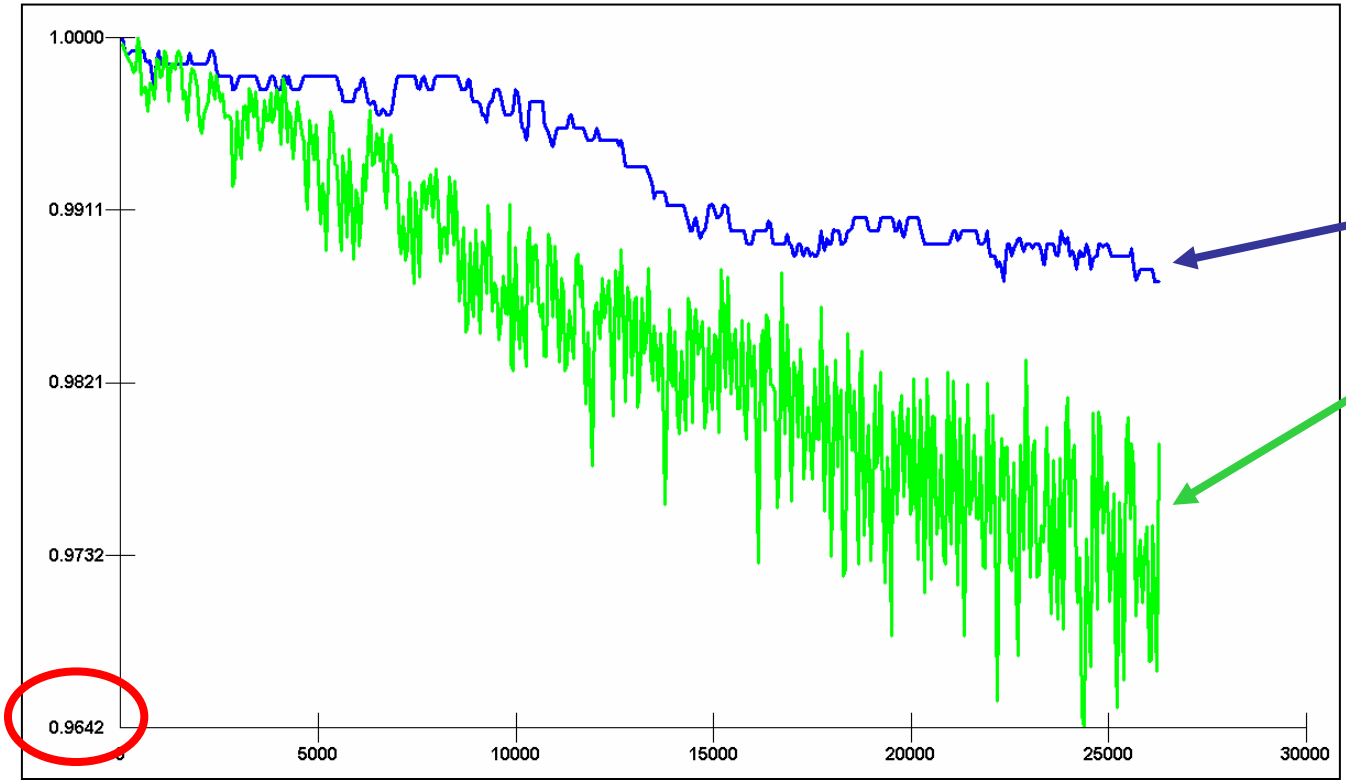
Simulation Results: Correct working of the Control System



Anyway the ACMS probability still decreases because the human element is only one item inside a more complex system.

Lower gradient of the AMCS perfomance is bound to the human element whose performances are renewed in every work shift while instead of the gradient of ACS performance that is due to the mechanical and electromechanical components that are subjected to ware out processes

Simulation Results: Uncontrolled failure event for the Cooling System



- x, operating hours
- y, event probability
- blue line ACMS performance
- green line ACS performance

Cooling system fails four times in three years.

- Operating average probability

  0.97 → 0.99

- ACS – 0.125 relevant accident/year
- AMCS – 0.025 relevant accident/year

Conclusion and Development

We had a reliability assessment of an electromechanical control system
We needed to foresee the usefulness of the introduction of the human controllers

As a result of the study, the simulations show qualitatively how important was the human control in the case study, reducing the dangerous situations.

⇨ Give a quantitative first approximation of the improvement

⇨ Appreciate only the human behaviour within a few well defined operating procedures

The present might be a possible way to be follow whenever it was necessary to conduct a feasibility study related to the introduction of human operators with control tasks.

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