



Reliability Study of an Intelligent Transmitter

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Overview

I. Introduction

- what is an intelligent transmitter?
- reliability issues for intelligent transmitters

II. “3-Step model”

- basic reliability modeling for intelligent transmitters
- case study on infrared gas transmitter

III. Reliability analysis

- relationship analysis between faults or failures and functions
- probabilities of malfunction and failure modes
- uncertainty analysis

IV. Design issues & Conclusion

I. Introduction

- **An intelligent transmitter**
 - incorporates signal conditioning and processing functions
 - is able to modify its internal behavior
 - sends measurement and status information
- **Functionalities enabled by digital technology**
 - error measurement correction
 - self-adjustment
 - self-diagnose and validation
 - online reconfiguration
 - digital and bidirectional communication

I. Introduction

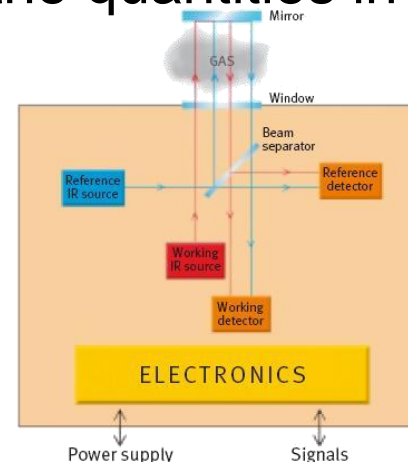
- **Reliability issues for intelligent transmitters**
 - system complexity i.e. numerous interactions between both material elements and functions
 - ***“3-Step model”: functions–material elements–failures***
 - system behavior under faulty conditions which is difficult to determine (e.g. due to programmable units and software)
 - ***relationship analysis between failures and functions***
 - several transmitted data may be wrong (e.g. measurement, status information), and dependently of each other
 - ***probabilities of malfunction and failure modes***
 - few available reliability feedback due to quite new technologies
 - ***uncertainty analysis***

II. “3-Step model”

- **Reliability modeling for intelligent transmitters**
 - **Goal Tree–Success Tree (GTST)** for both functional analysis and system breaking up
 - **Master Logic Diagram (MLD)** for inter and intra relationships between elements
 - list of **Faults and Failures** for reliability purpose
- **Notes**
 - GTST–MLD has been developed by M. Modarres *et al.*, 1999
 - used by A. Jalashgar, 1998 to identify complex system failures
 - Y. Hu *et al.*, 1999 has proposed system behavior evaluations
 - hereby, faults and failures are drawn up as a third full part for reliability analyses

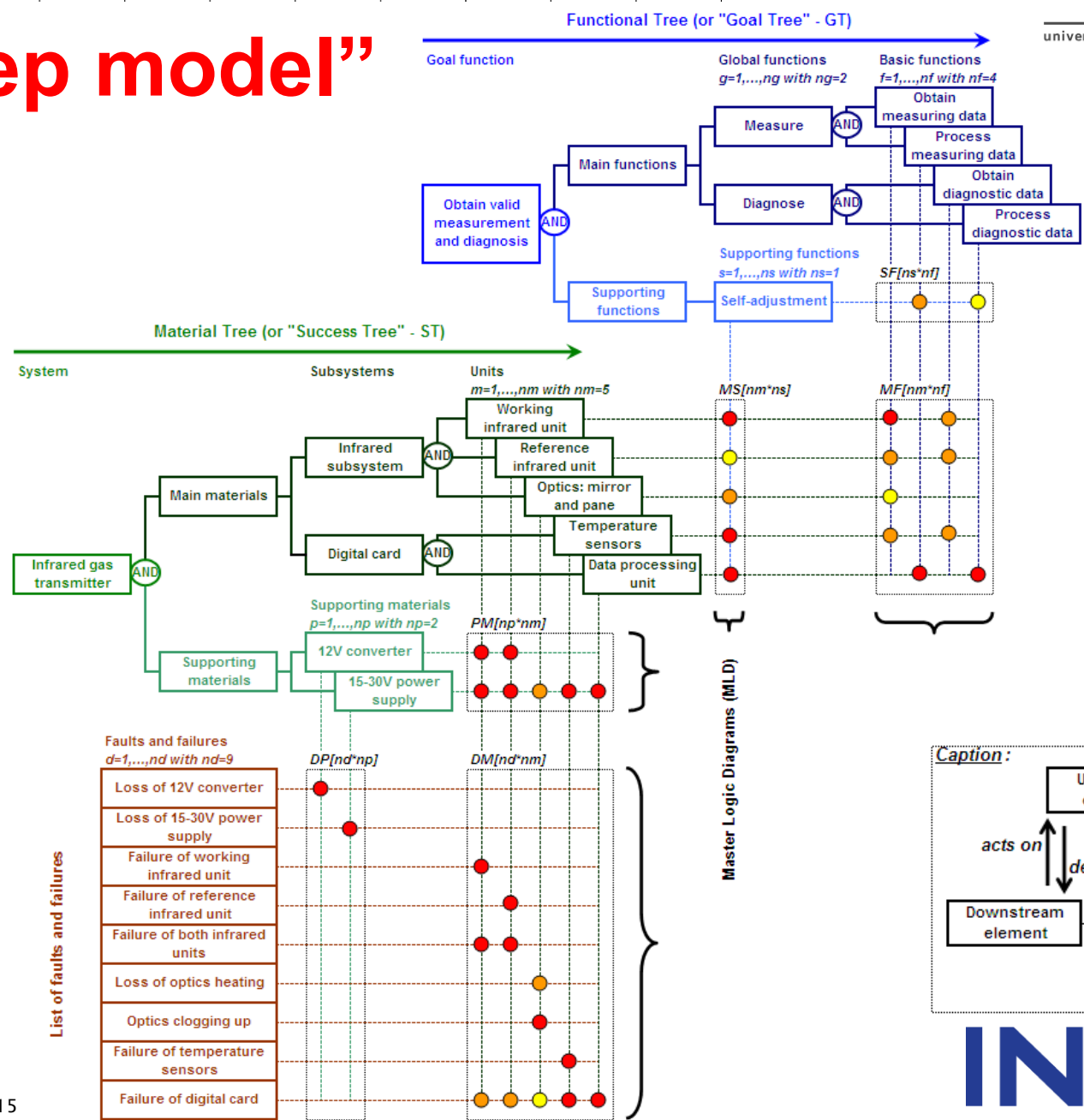
II. “3-Step model”

- **Case study on infrared gas transmitter**
 - to measure gas concentration by infrared absorption
 - the use of a working and a reference infrared units allows corrections of the optics clogging up and power fluctuations
 - heating elements aim to prevent steam from building up on optics
 - temperature sensors are used for digital compensation
 - self-adjustments of the off-set and gain drift are performed
 - diagnosis functions check the quantities in acceptable ranges



II. "3-Step model"

- Graph



Caption:

Upstream element relationship Downstream element

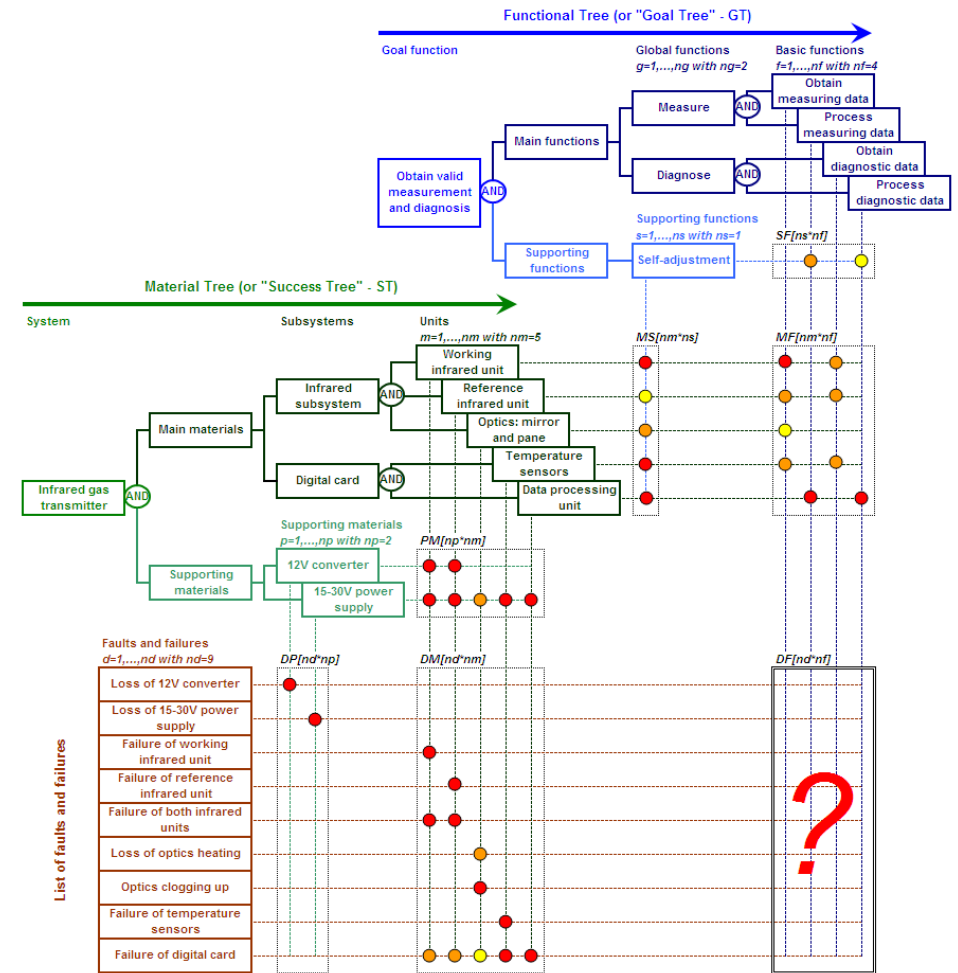
- full / high
- medium
- low
- nil / very low

acts on (upward arrow), depends on (downward arrow)

III. Reliability analysis

- Relationship analysis
 - what is the probability that a downstream element failure implies the failure of any upstream element?
 - input MLD components give direct stochastic relationships

full / high	1.00
medium	0.67
low	0.33
nil / very low	0.00
 - this problem can be translated into classical models to be solved by Boolean reliability tools



III. Reliability analysis

Relationship analysis

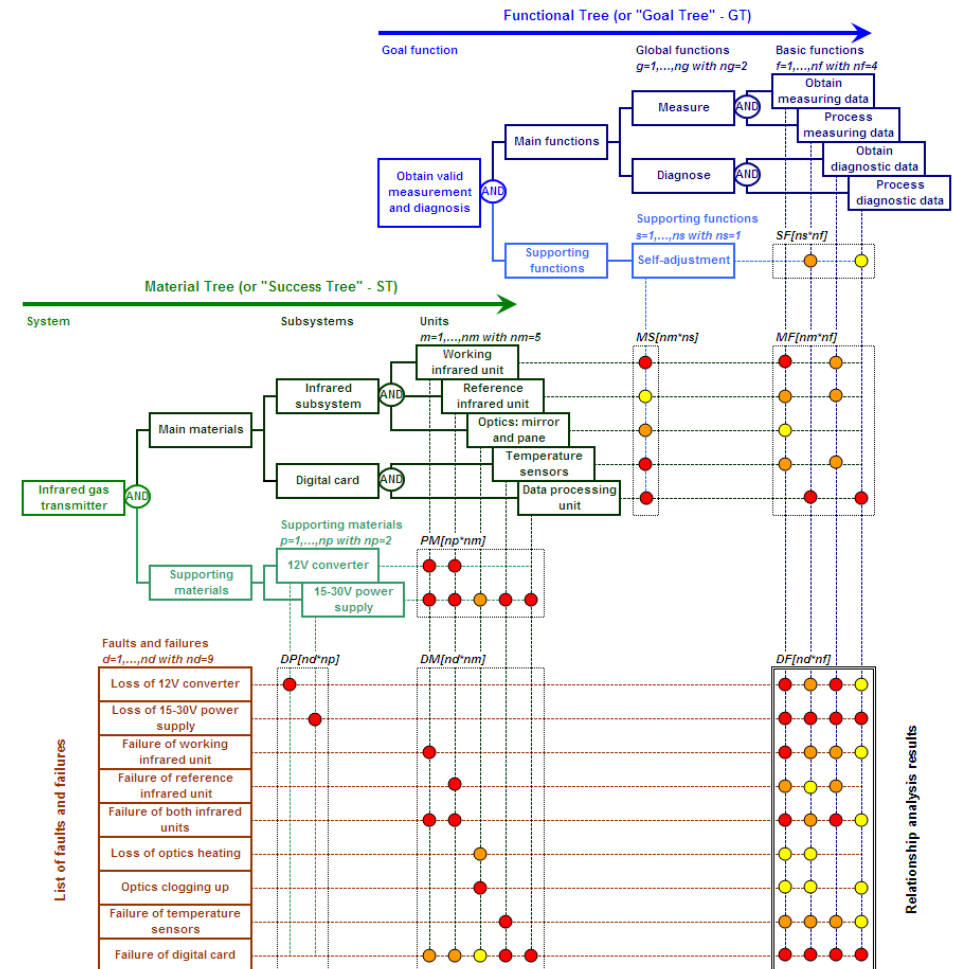
- translation of results

full / high	0.83 to 1.00
medium	0.50 to 0.83
low	0.17 to 0.50
nil / very low	0.00 to 0.17

- MLD component between fault or failure d and function f

$P[DF_{d,f}] = \text{probability that the failure of function } f \text{ occurs, given fault or failure } d \text{ has occurred and not any other}$

- the same approach is applied to main / global functions g

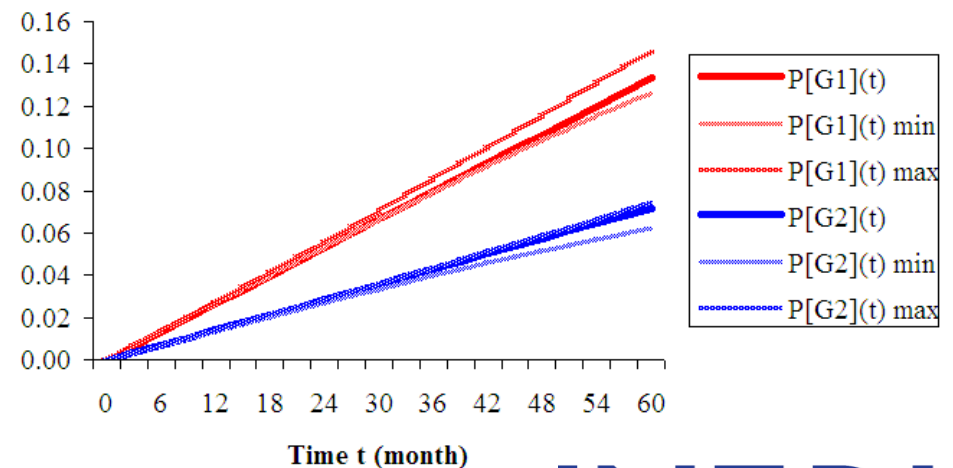


III. Reliability analysis

• Probabilities of malfunction

- inputs: $P[D_d](t)$ = probability of fault or failure d at time t
- results: $P[G_g](t)$ = probability of failure of main function g at time t with $g = 1$ for **measure** and $g = 2$ for **diagnose**
- these probabilities can be obtained by classical reliability tools
- a simple interval:
$$\sum_d \left(P[G_{d,g}] \cdot P[G_g] \prod_{\delta \neq d} (1 - P[D_\delta]) \right) \leq P[G_g] \leq \sum_d \left(P[G_{d,g}] \cdot P[G_g] \prod_{\delta \neq d} (1 - P[D_\delta]) \right)$$

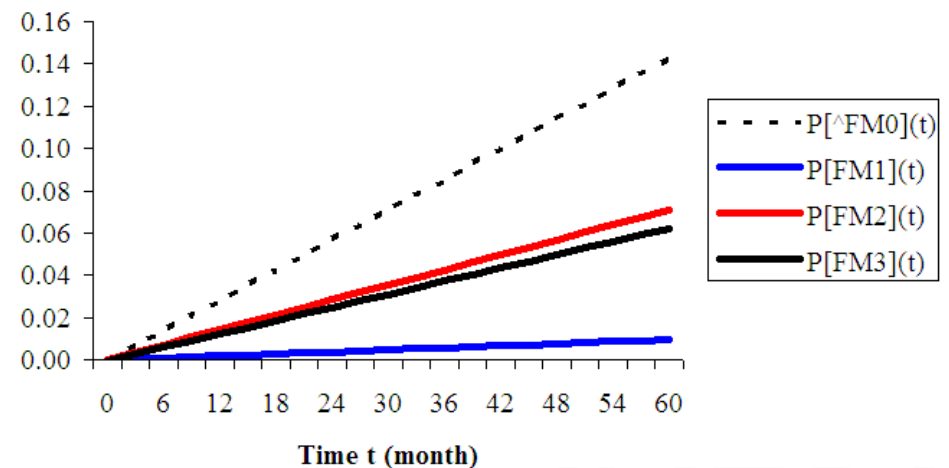
Fault or failure d	Probability of fault or failure d at time t i.e. $P[D_d](t)$
1	$1 - \exp(-5 \cdot 10^{-8} \cdot t)$
2	$1 - \exp(-5 \cdot 10^{-8} \cdot t)$
3	$1 - \exp(-4 \cdot 10^{-7} \cdot t)$
4	$1 - \exp(-4 \cdot 10^{-7} \cdot t)$
5	$1 - \exp(-1 \cdot 10^{-7} \cdot t)$
6	$1 - 3 \cdot \exp(-6 \cdot 10^{-6} \cdot t) + 2 \cdot \exp(-9 \cdot 10^{-6} \cdot t)$
7	$1 - \exp(-3 \cdot 10^{-6} \cdot t)$
8	$1 - 2 \cdot \exp(-5 \cdot 10^{-7} \cdot t) + \exp(-1 \cdot 10^{-8} \cdot t)$
9	$1 - \exp(-2 \cdot 10^{-7} \cdot t)$



III. Reliability analysis

- **Probabilities of failure modes**
 - failure modes are defined according to main function fulfillments
 - these failure modes form a set partition
 - results: $P[FMx](t) = \text{probability of failure mode } x \text{ at time } t$
 - these probabilities can be obtained by classical reliability tools

Failure mode	State of global function <i>measure</i>	State of global function <i>diagnose</i>
<i>FM0</i>	functioning (event $\wedge G1$)	functioning (event $\wedge G2$)
<i>FM1</i>	functioning (event $\wedge G1$)	malfunctioning (event $G2$)
<i>FM2</i>	malfunctioning (event $G1$)	functioning (event $\wedge G2$)
<i>FM3</i>	malfunctioning (event $G1$)	malfunctioning (event $G2$)

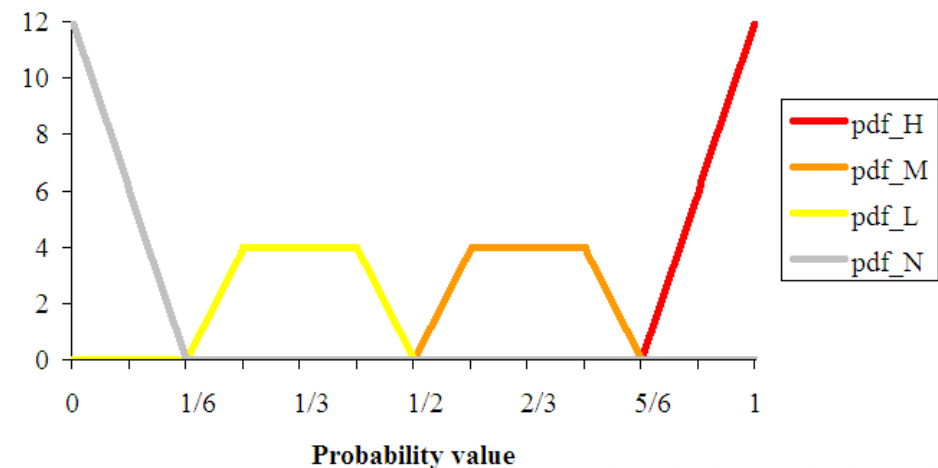


III. Reliability analysis

- **Uncertainty analysis**

- it is often quite difficult to assess the direct relationships between elements i.e. input probabilities given by MLD components
- ***do the input relationships question the results?***
- the values of relationships are now assumed random variables i.e. probability values are described by probability distributions

Relation-ship	Random variable	Expec-tancy	Variance
high	H	0.94	$1.5 \cdot 10^{-3}$
medium	M	0.67	$5.8 \cdot 10^{-3}$
low	L	0.33	$5.8 \cdot 10^{-3}$
very low	N	0.06	$1.5 \cdot 10^{-3}$

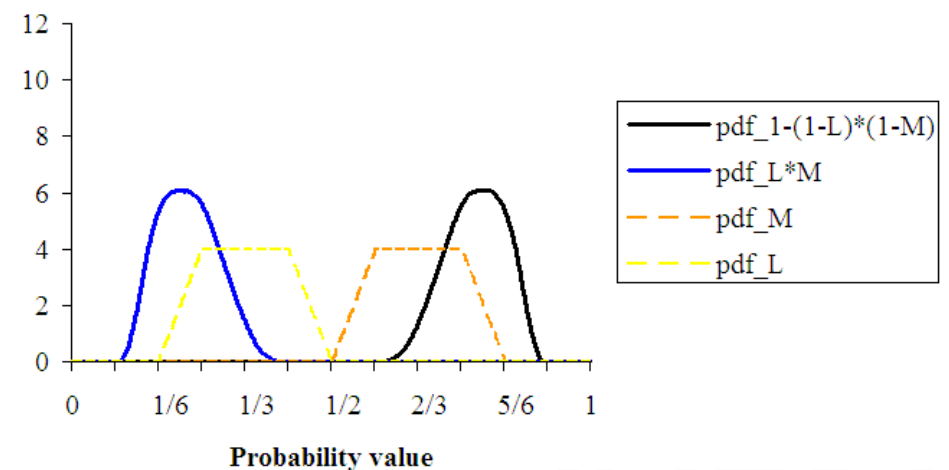


III. Reliability analysis

- **Uncertainty analysis**

- uncertainty analysis is performed on relationship analysis results between fault or failure d and main function g i.e. $P[DG_{d,g}]$
- 10,000 draws of Monte Carlo simulations have been used
- **variances of results are orders of magnitude lower than input**
→ by combining input probabilities, variances can be reduced

Fault or failure d	Impact on <i>measure</i> i.e. $P[DG_{d,1}]$		Impact on <i>diagnose</i> i.e. $P[DG_{d,2}]$	
	Expectancy	Variance	Expectancy	Variance
1	0.99	$6.6 \cdot 10^{-5}$	0.93	$5.7 \cdot 10^{-4}$
2	1.00	$4.4 \cdot 10^{-7}$	1.00	$9.8 \cdot 10^{-6}$
3	0.97	$2.3 \cdot 10^{-4}$	0.83	$2.1 \cdot 10^{-3}$
4	0.85	$2.1 \cdot 10^{-3}$	0.80	$2.9 \cdot 10^{-3}$
5	0.99	$3.5 \cdot 10^{-5}$	0.94	$4.8 \cdot 10^{-4}$
6	0.74	$5.0 \cdot 10^{-3}$	0.54	$7.8 \cdot 10^{-3}$
7	0.81	$3.0 \cdot 10^{-3}$	0.58	$6.7 \cdot 10^{-3}$
8	0.92	$8.6 \cdot 10^{-4}$	0.84	$2.1 \cdot 10^{-3}$
9	1.00	$1.2 \cdot 10^{-6}$	1.00	$1.1 \cdot 10^{-5}$



IV. Design issues & Conclusion

- **Design issues**
 - to analyze “intelligent” functionalities on transmitter reliability
 - to define importance criteria for material elements which take the impacts on critical functions into account
 - to define a “failure coverage” depending on function fulfillments
 - to optimize the control system decision rules by taking the failure mode probabilities into account
- **The proposed model for reliability study**
 - deals with interactions between material elements and functions
 - deals with undetermined system behavior under faulty conditions
 - deals with input uncertainties

→ appropriate for intelligent transmitter reliability analyses



Thanks for your attention

Questions & Comments are Welcome

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