BAYESIAN NETWORK APPROACH FOR GAS PATH FAULT DIAGNOSIS

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Bayesian Network Approach for Gas Path Fault Diagnosis

- The problem of Gas Path fault diagnosis
- Bayesian Belief Networks for Gas Path fault diagnosis
  - o Elements of Bayesian Belief Networks (BBN)
  - o Set up of the diagnostic BBN
- Overall diagnostic procedure
- Evaluation of the network
  - o Effect of noise level and operating conditions
  - o Benchmark fault cases
- Summary - Conclusions

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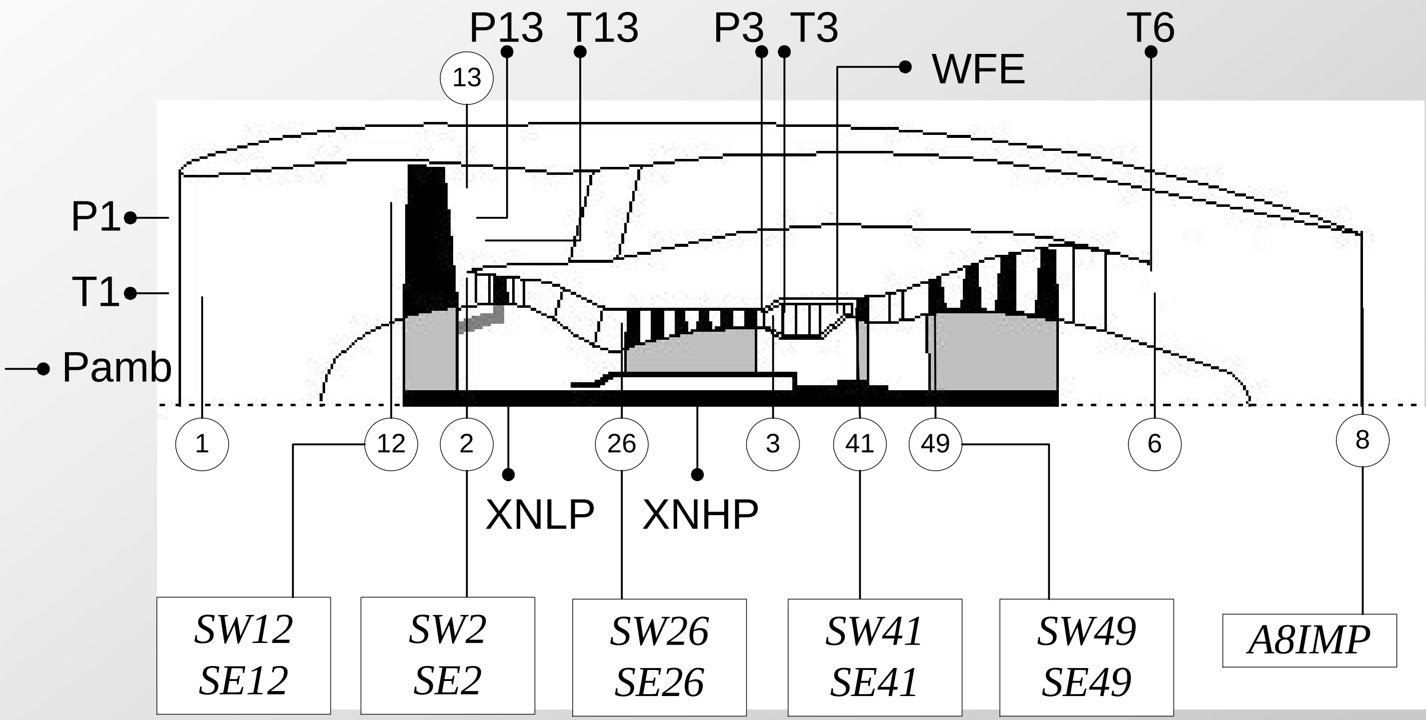
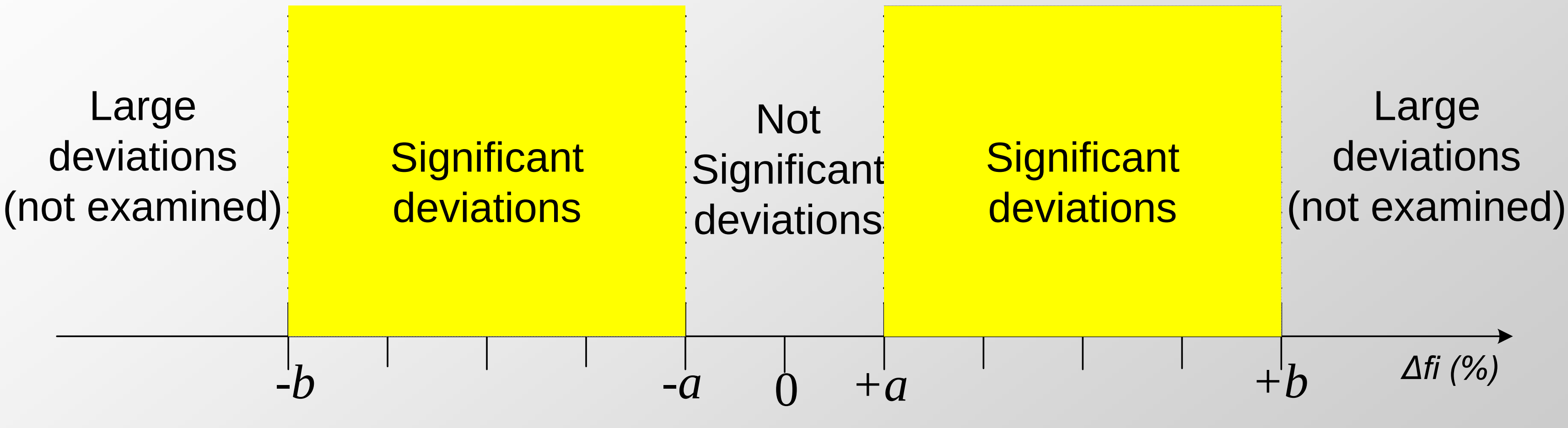
The problem of Gas Path fault diagnosis

Detect health parameters that may deviate due to component faults



High-by-Pass ratio, partially mixed, turbofan engine used as a test case

The problem of Gas Path fault diagnosis



Component faults cause significant deviations on corresponding health parameters

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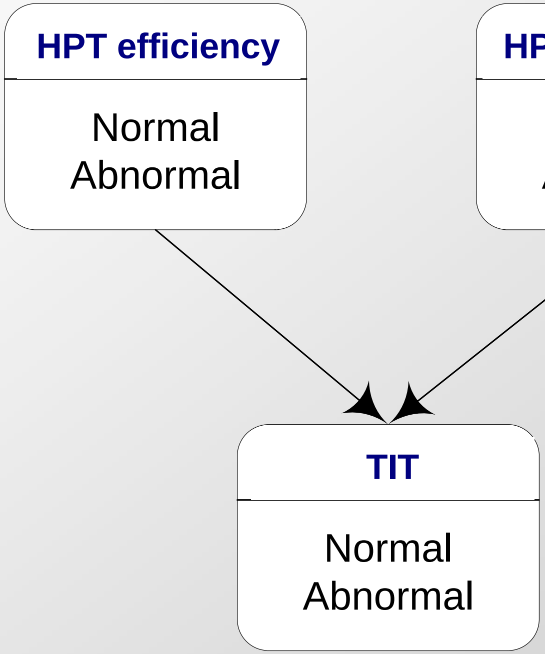
Elements of Bayesian Belief Networks (BBN)

HPT efficiency	
Normal	0.90
Abnormal	0.10

HPT flow factor	
Normal	0.80
Abnormal	0.20

A BBN consists of:

- -Nodes
- -Links
- -States
- -CPTs

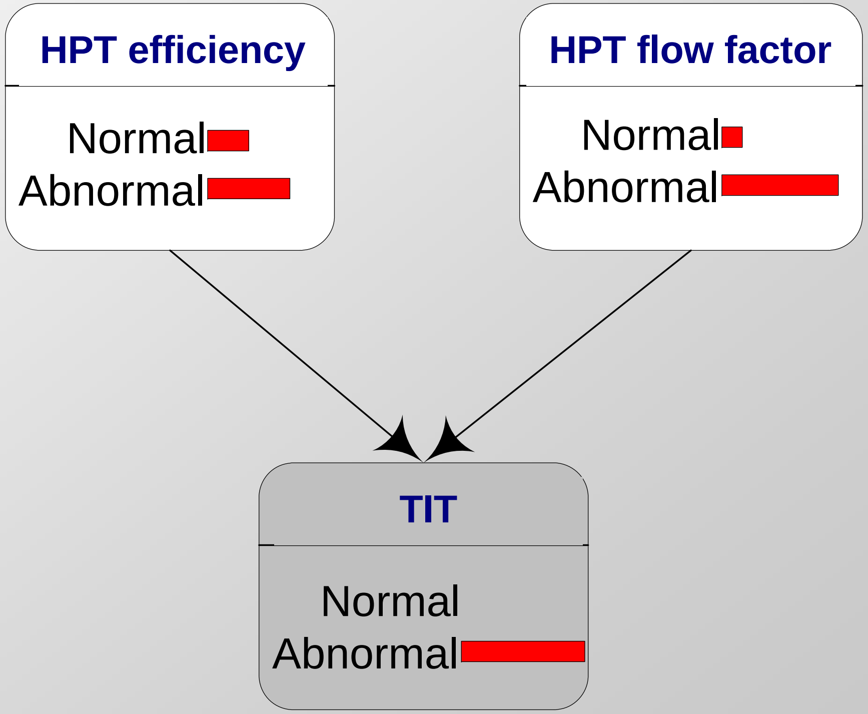


HPT efficiency	Normal		Abnormal	
HPT flow factor	Normal	Abnormal	Normal	Abnormal
Normal	0.95	0.60	0.70	0.20
Abnormal	0.05	0.40	0.30	0.80

Inference with Bayesian Belief Networks

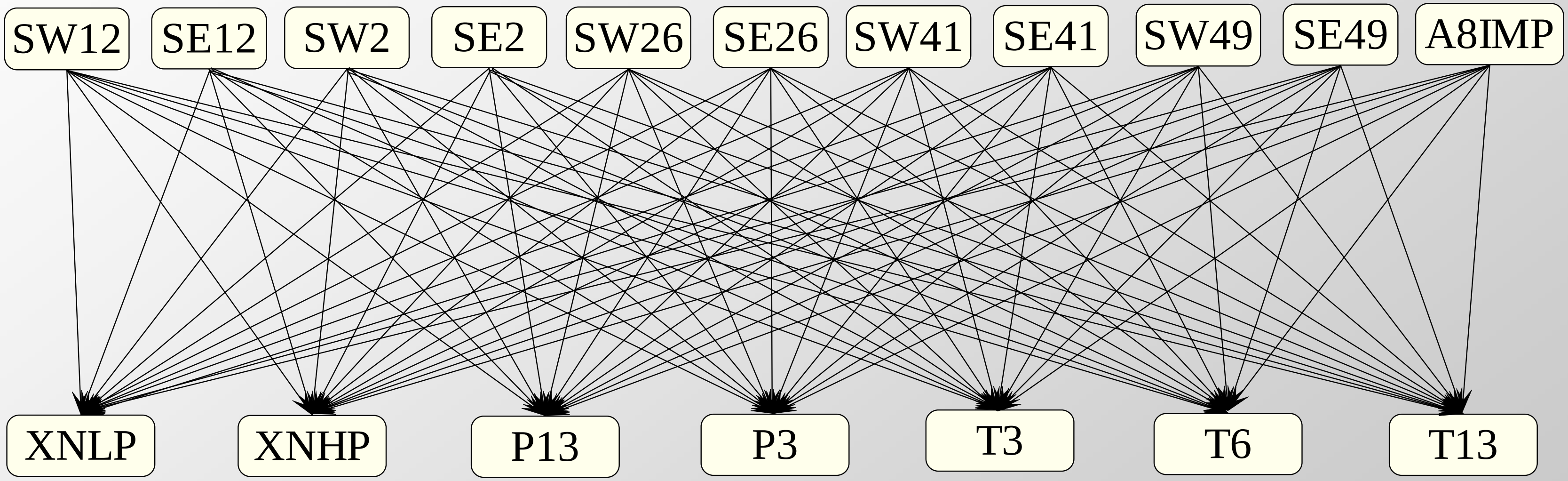
Once evidence is available,

BBN estimates probabilities for all states of nodes



The diagnostic BBN for Gas Path faults

Architecture extracted from system of equations: $\bar{Y} = g(\bar{f})$



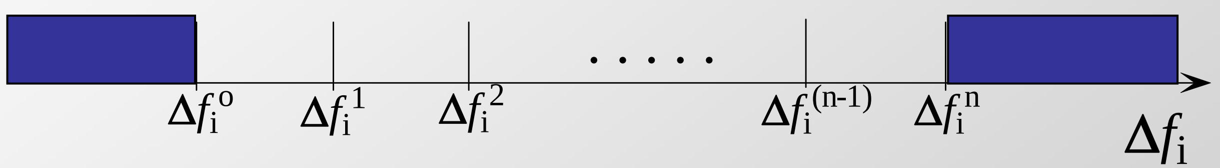
Nodes: Gas Path variables

Links: From independent to dependent variables

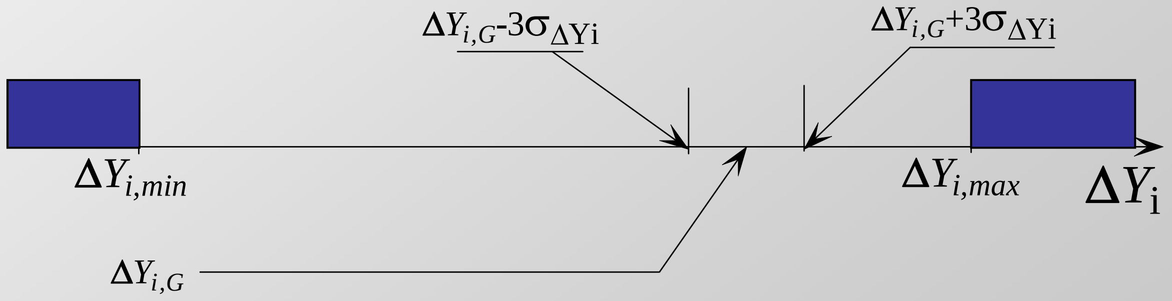
States of nodes

States represent intervals of deviations from nominal value

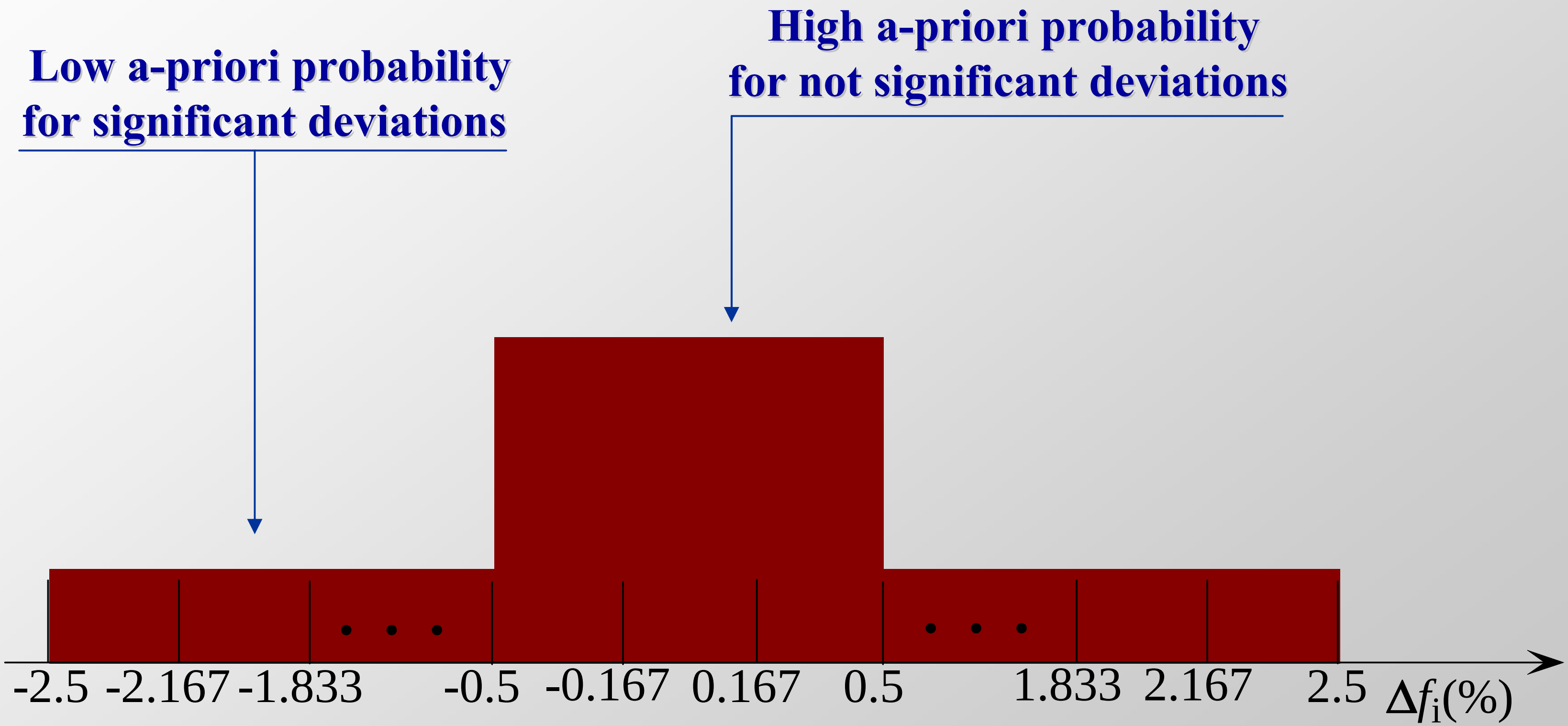
a) States of the health parameter nodes:



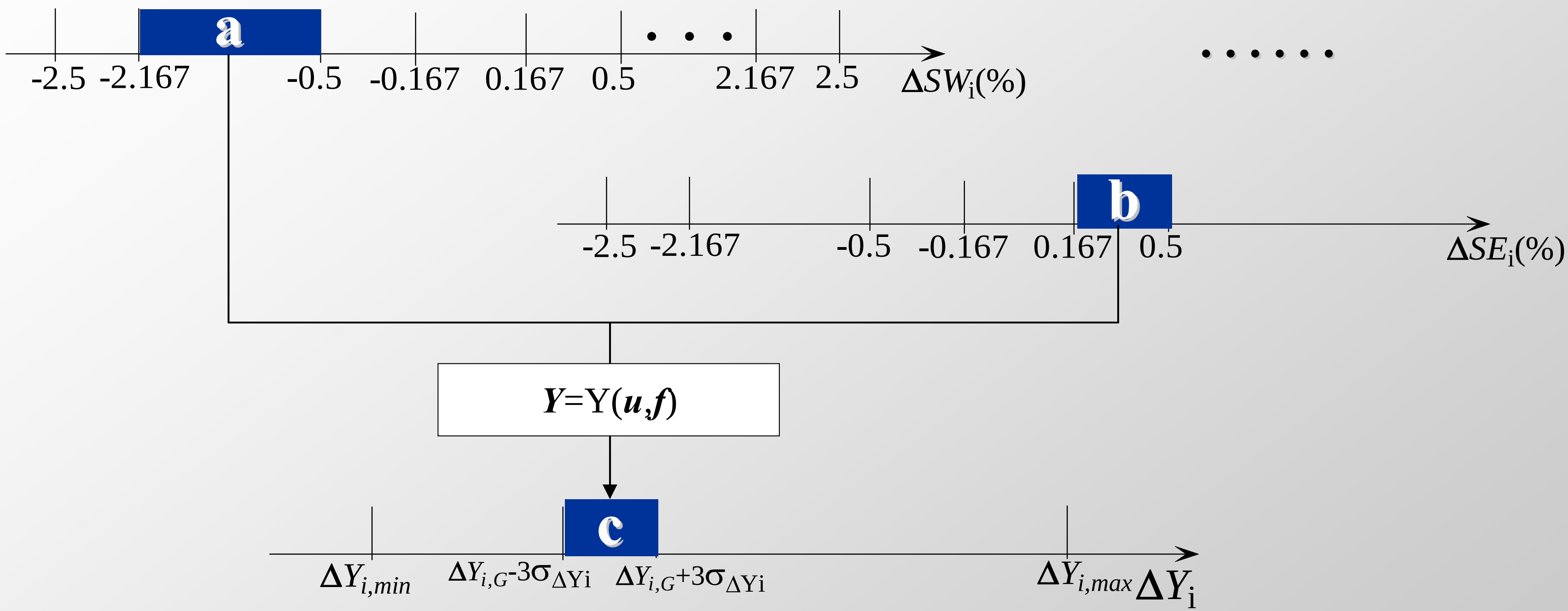
b) States of the measurement nodes:



A priori probabilities



Conditional Probability Tables

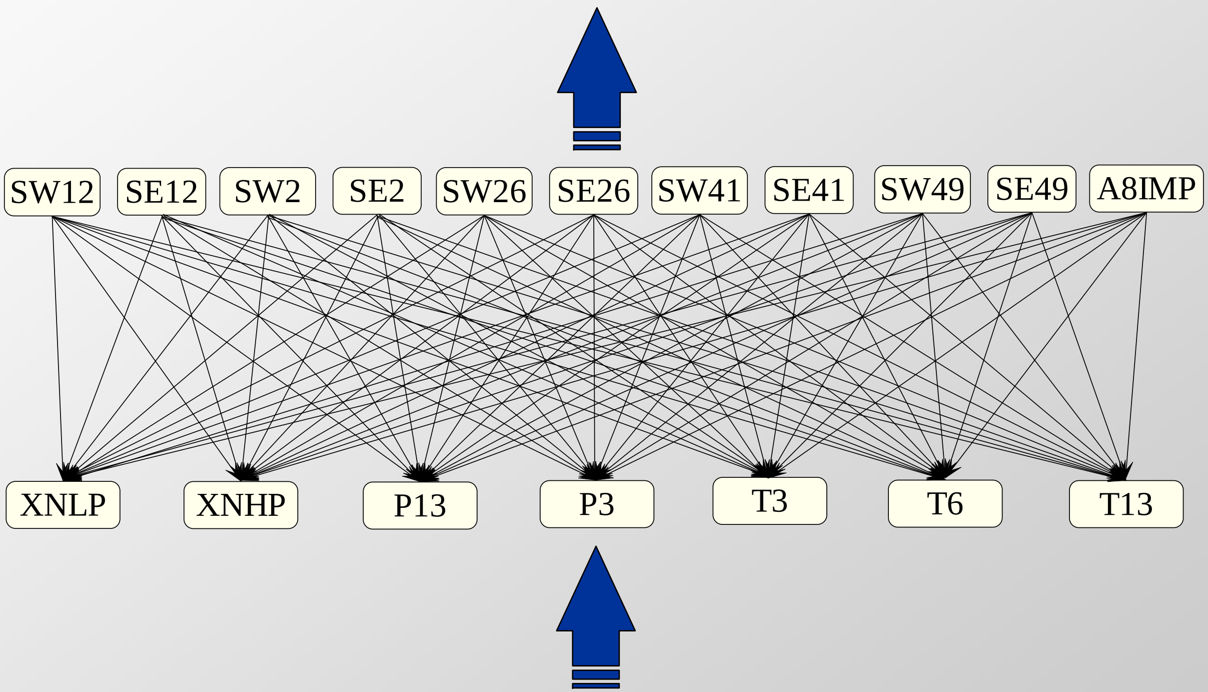


SWi						a	
. . .		. . .		. . .		. . .	
SEi						b	
c				. . .			

$P(\Delta Y_i \in c \mid \Delta SW_i \in a, \ldots, \Delta SE_i \in b)$

Summation of input-output information of BBN

P(Δf_i | ΔXNLP, ΔXNHP, …, ΔT13)



ΔXNLP, ΔXNHP, …, ΔT13

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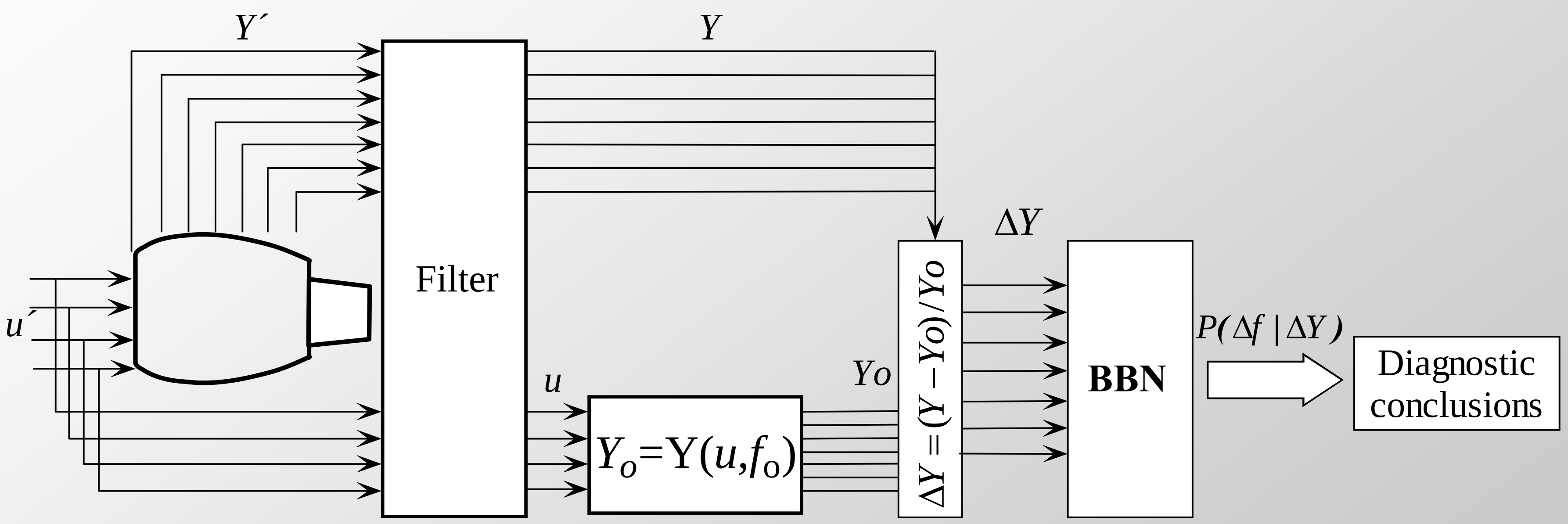
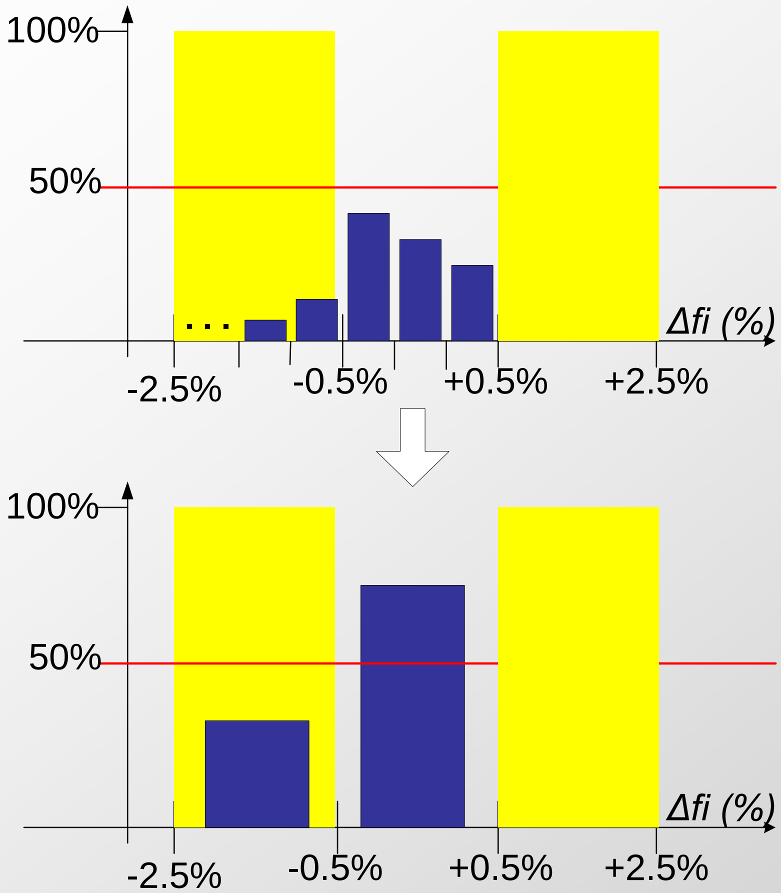
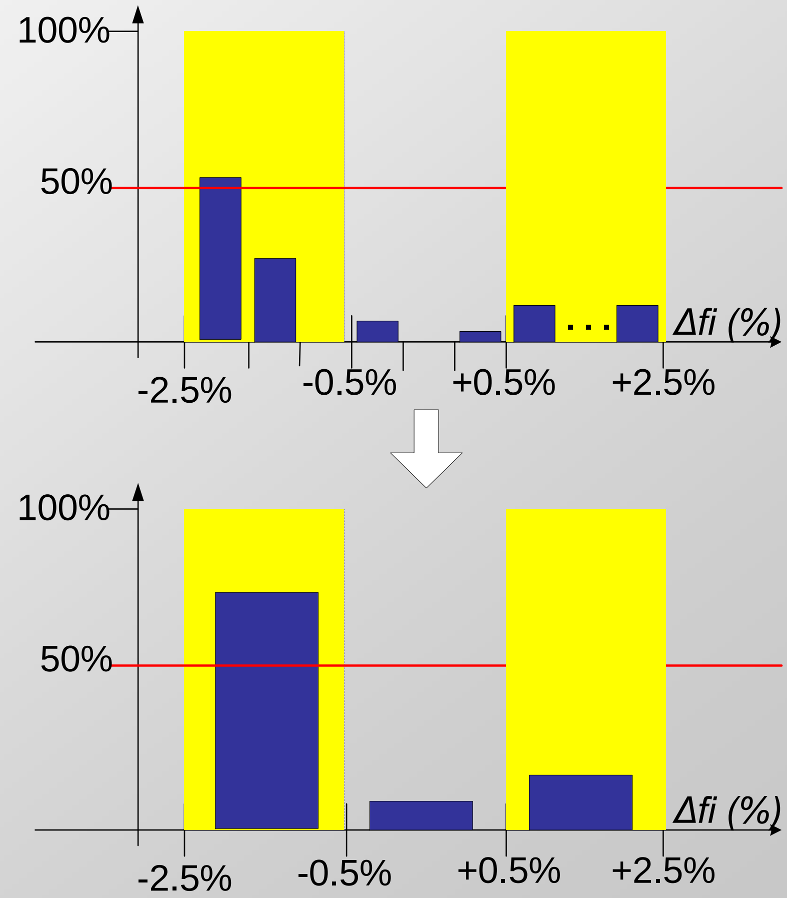
Overall diagnostic procedure



Extracting diagnostic conclusions



Parameter NOT significantly deviated



Parameter significantly deviated

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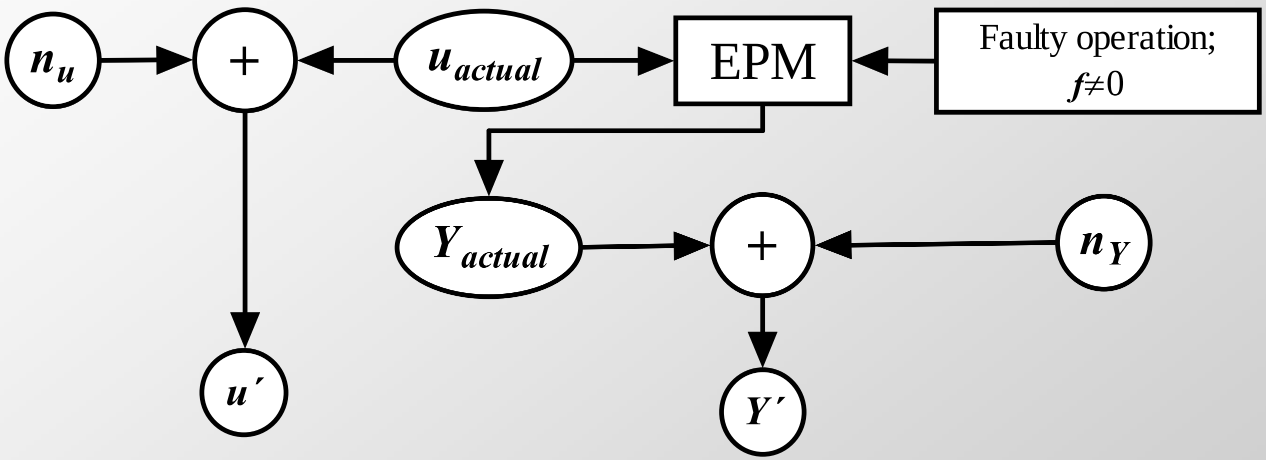
Simulation of fault cases for evaluation



Measurement data are simulated through an Engine Performance Model and random noise

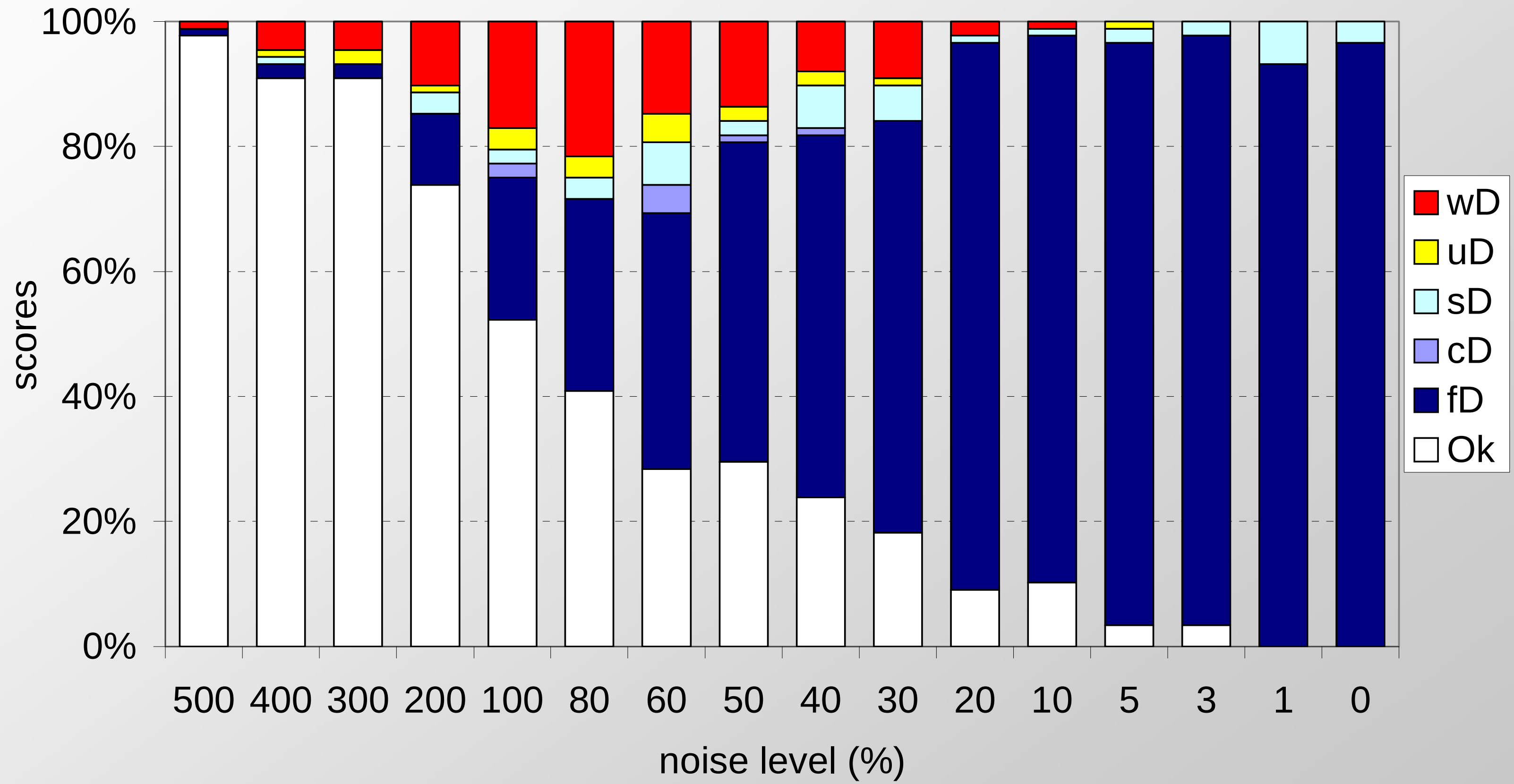
BBN behavior in the presence of Noise

How the diagnostic ability is affected by the presence of noise?

Noise ‘blurs’ the diagnosis

Filtering of measurement data may improve significantly the performance of the network

Effect of Noise Level



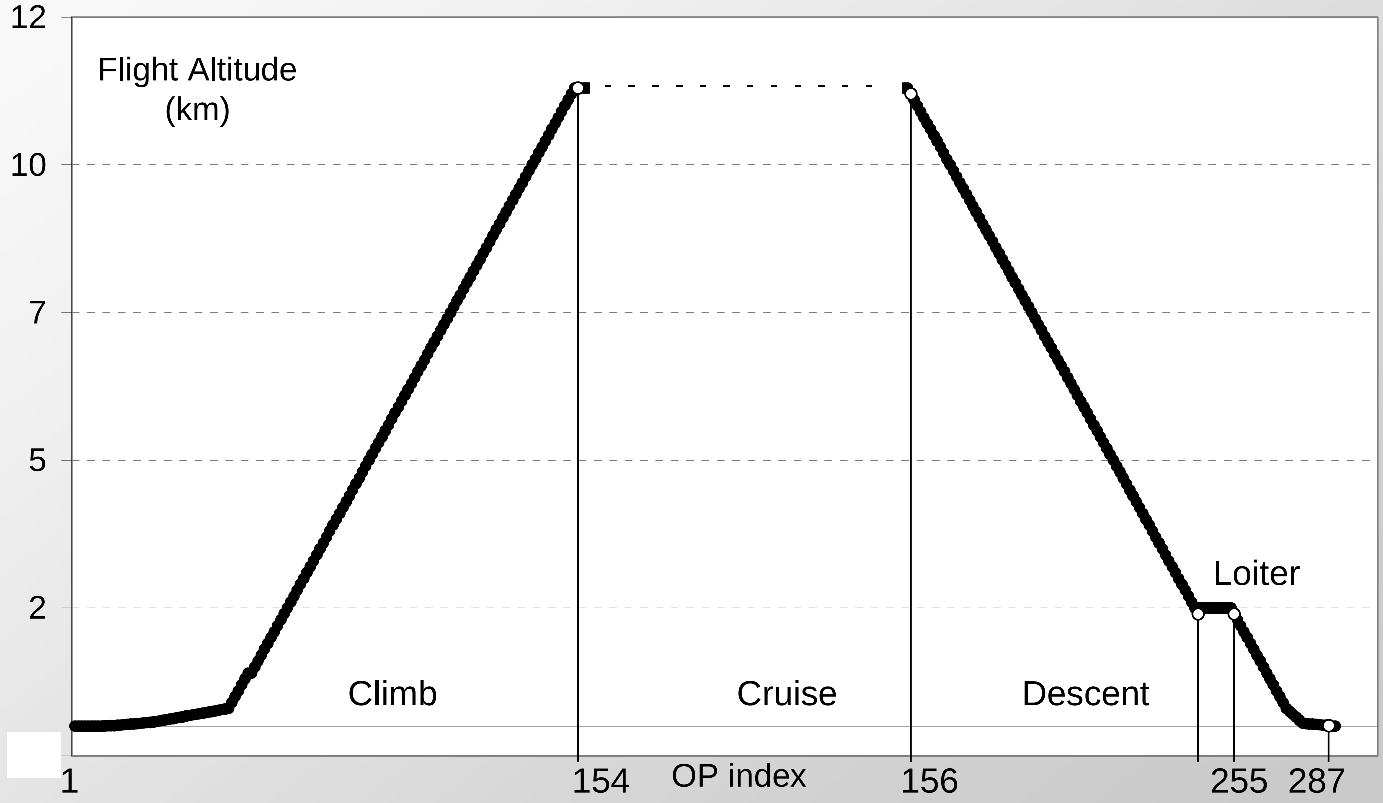
Diagnosis at different Operating Conditions

How the diagnostic ability is affected at different operating conditions?

Diagnostic ability unaffected for operating points ranging from take-off to cruise conditions

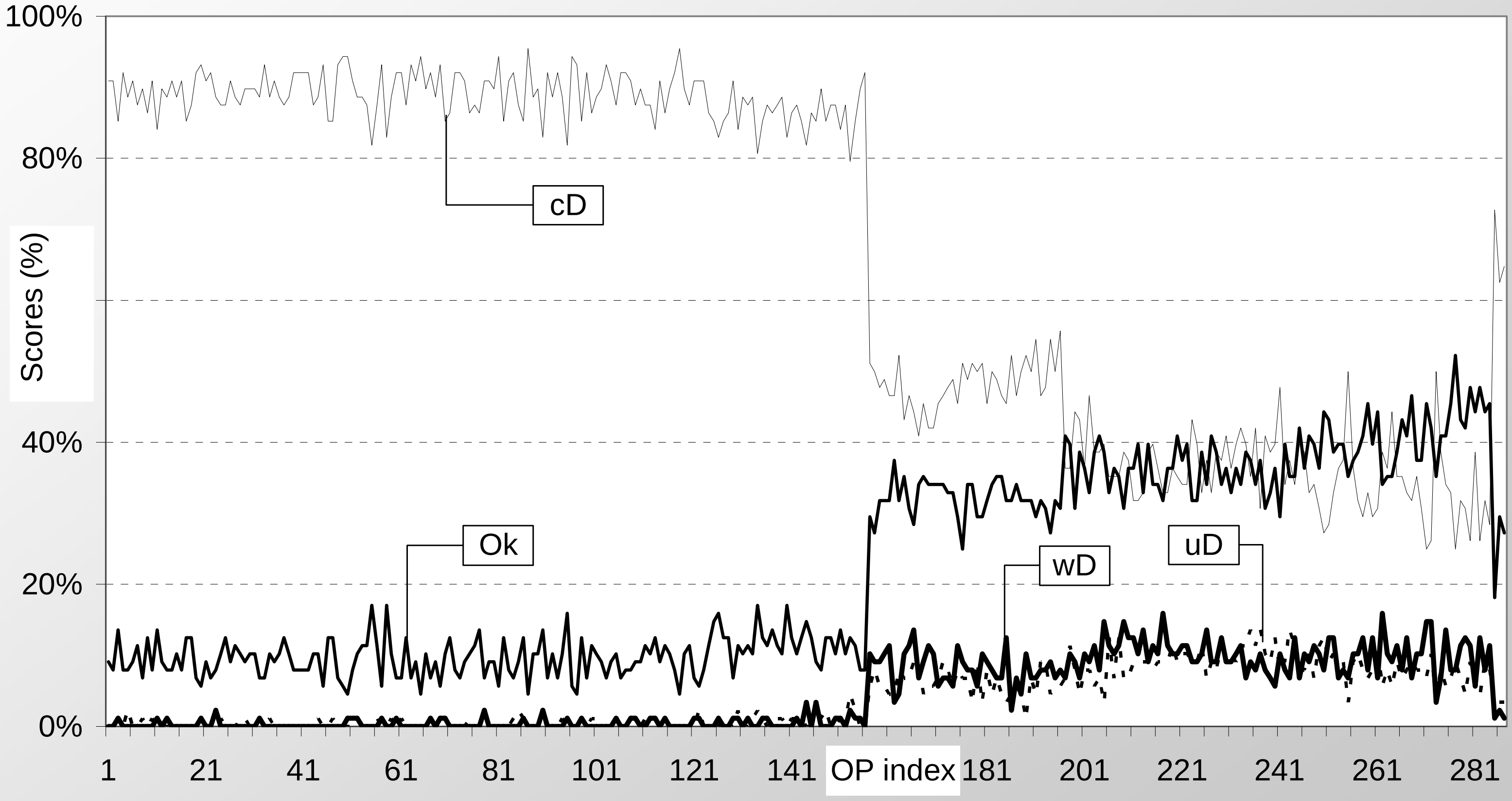
Considered Operating Conditions

Representation of a flight envelope



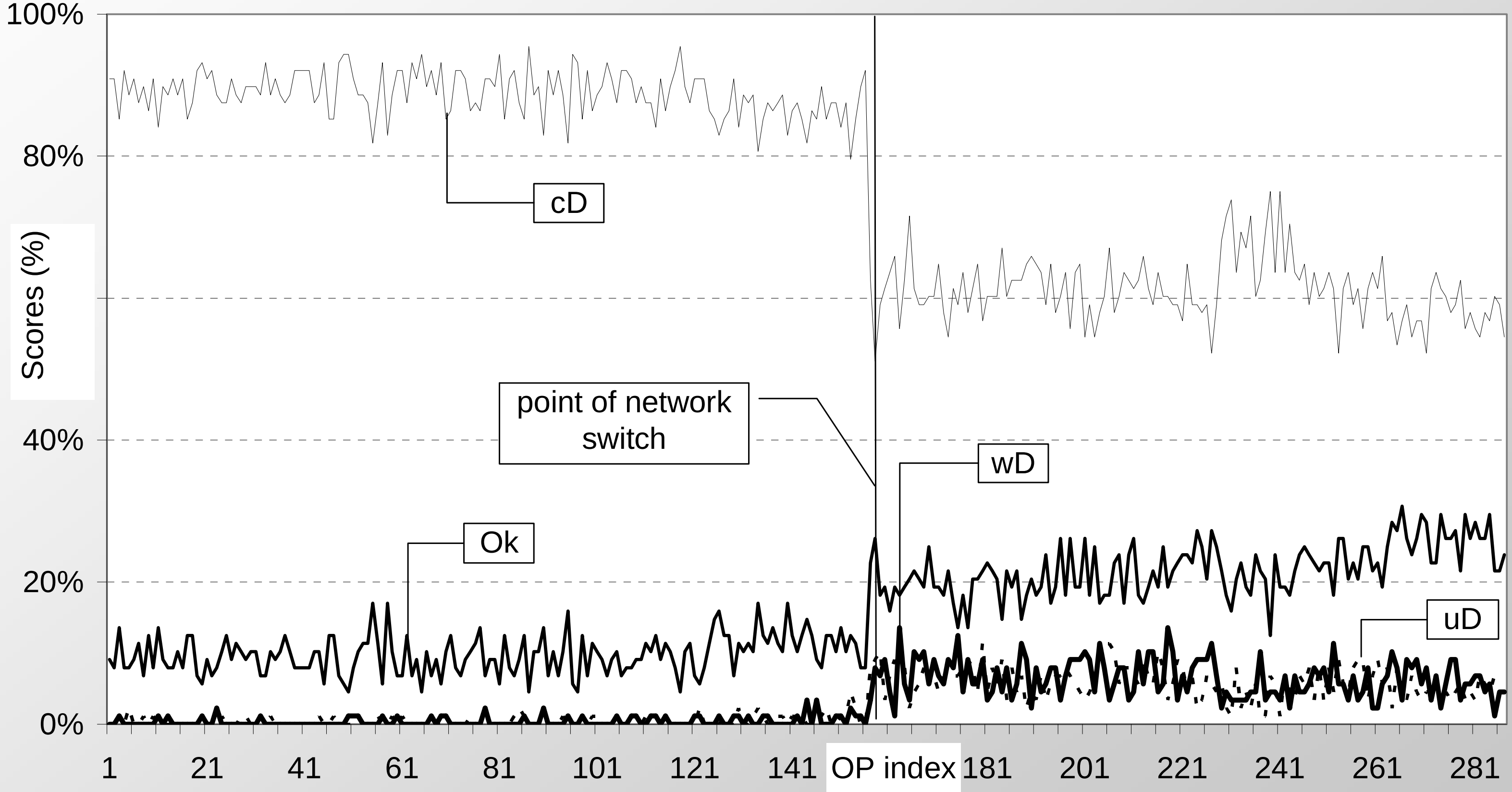
Effect of Operating Conditions

The considered network used for the whole flight envelope



Effect of Operating Conditions

A pair of networks considered to cover the flight envelope



Benchmark fault cases

Fault Case	Affected components
a	LPC
b	
c	HPC
d	
e	
f	HPT
g	
h	
I	LPT
j	
k	
l	
m	Nozzle
n	
o	

Evaluation of BBN on the benchmark fault cases

Fault Case	*Actual Deviations of Health Parameters*	*Factors found significantly deviated*	*Class Diagnosis*
a	SW2, SE2, SW12, SE12	SW12	sD
b	SE12	SE12	fD
c	SW26, SE26	SE2	sD
d	SE26	SE26	fD
e	SW26	SW26	fD
f	SW41	SW41	fD
g	SW41, SE41	SW41, SE41	fD
h	SE41	SE41	fD
I	SE49	SE49	fD
j	SW49, SE49	SE41	sD
k	SW49	SW49	fD
l	SW49, SE49	SW49, SE49	fD
m	A8IMP	A8IMP	fD
n	A8IMP	A8IMP	fD
o	A8IMP	A8IMP	fD

Evaluation of BBN on the benchmark fault cases

BBN with additional measurements (P42, T42)

Fault Case	*Actual Deviations of Health Parameters*	*Factors found significantly deviated*	*Class Diagnosis*
a	SW2, SE2, SW12, SE12	SW12	sD
b	SE12	SE12	fD
c	SW26, SE26	SW26, SE2	sD
d	SE26	SE26	fD
e	SW26	SW26	fD
f	SW41	SW41	fD
g	SW41, SE41	SW41, SE41	fD
h	SE41	SE41	fD
I	SE49	SE49	fD
j	SW49, SE49	SW49, SE49	fD
k	SW49	SW49	fD
l	SW49, SE49	SW49, SE49	fD
m	A8IMP	A8IMP	fD
n	A8IMP	A8IMP	fD
o	A8IMP	A8IMP	fD

Evaluation of BBN on the benchmark fault cases

BBN with modified a-priori probabilities

Fault Case	*Actual Deviations of Health Parameters*	*Factors found significantly deviated*	*Class Diagnosis*
a	SW2, SE2, SW12, SE12	SW12	sD
b	SE12	SE12	fD
c	SW26, SE26	SW26, SE26	fD
d	SE26	SE26	fD
e	SW26	SW26	fD
f	SW41	SW41	fD
g	SW41, SE41	SW41, SE41	fD
h	SE41	SE41	fD
I	SE49	SE49	fD
j	SW49, SE49	SE41	sD
k	SW49	SW49	fD
l	SW49, SE49	SW49, SE49	fD
m	A8IMP	A8IMP	fD
n	A8IMP	A8IMP	fD
o	A8IMP	A8IMP	fD

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Summary - Conclusions

- Easy to built network from mathematical models

- Ability to handle the problem of fewer measurements than parameters in GPA

- Wide range of effective diagnosis

- Ability to incorporate information from sources of different nature