SETTING UP A BELIEF NETWORK FOR TURBOFAN DIAGNOSIS WITH THE AID OF AN ENGINE PERFORMANCE MODEL

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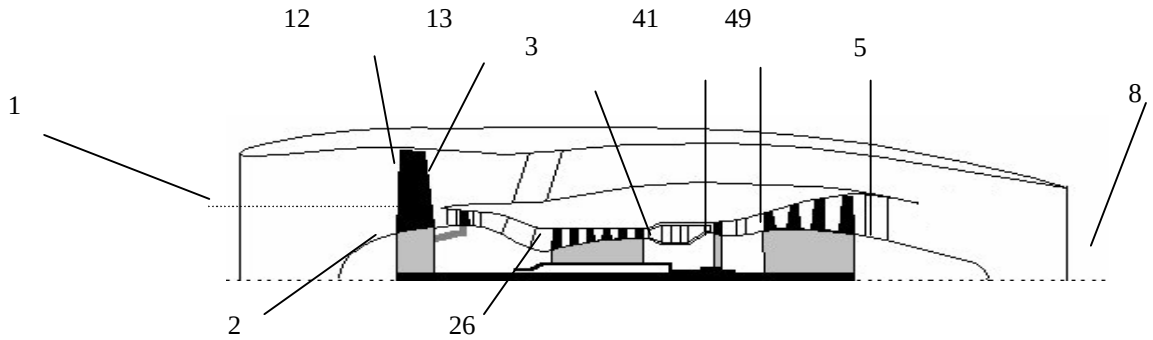
- § Formulation of the diagnostic problem
- § Features of Bayesian Belief Networks (BBN)
- § Study of the diagnostic performance of BBN
- § Summary - Conclusions

Formulation Of The Diagnostic Problem (I)

OBJECTIVE: BBN to diagnose component faults of High-by-Pass ratio, partially mixed, turbofan engine



Layout of a turbofan engine and station numbering for positions of interest.

Formulation Of The Diagnostic Problem (II)

ØInformation Provided

§Quantities defining the operating Conditions(4)

§ Ambient Conditions

§ Flight Speed

§Set Point Variable (Fuel Flow Rate)

§Quantities for Deducing Engine Condition (7)

§ Shafts' speeds

§ Pressure, Temperature

ØInformation Required

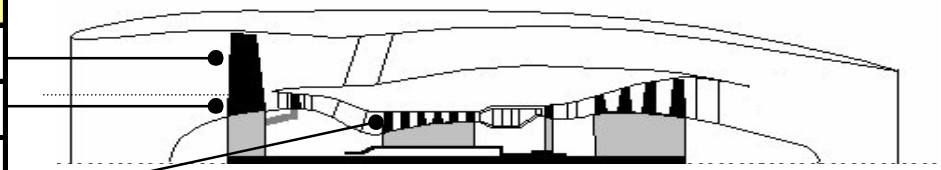
§Condition of individual engine components

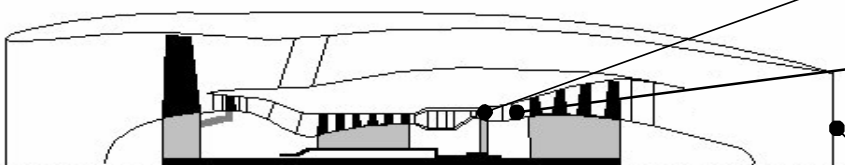
§Kind, Location, Severity (magnitude) of faults

Turbofan Engine Modeling

Positions of interest

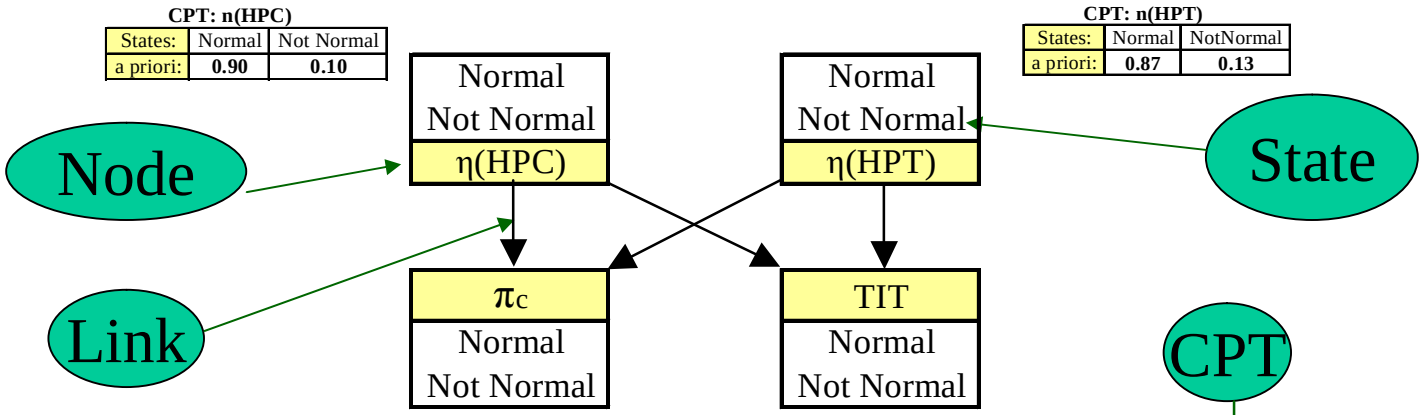
Related Factors	Modules
SW12, SE12	Outer Fan
SW2, SE2	Inner Fan
SW26, SE26	High Pressure Compressor





Modules	Related Factors
High Pressure Turbine	SW41, SE41
Low Pressure Turbine	SW49, SE49
Exhaust Area	A8IMP

Elements of BBN



CPT: n(HPC)

States:	Normal	Not Normal
a priori:	**0.90**	**0.10**

CPT: n(HPT)

States:	Normal	NotNormal
a priori:	**0.87**	**0.13**

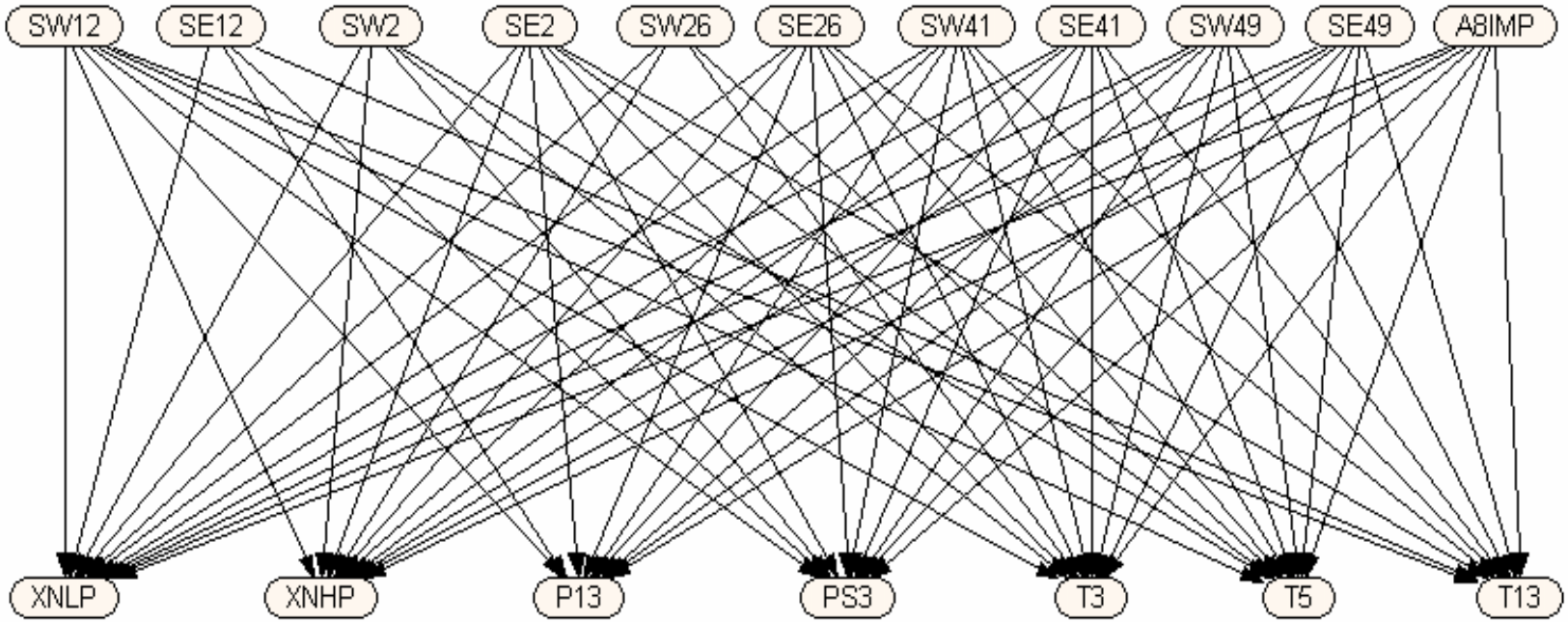
CPT: πc

States	Normal	Not Normal	n(HPC)	n(HPT)	Parents
Conditional Probabilities	**0.97**	**0.03**	Normal	Normal	States of parents
	0.68	**0.32**	Normal	Not Normal	
	0.26	**0.74**	Not Normal	Normal	
	0.02	**0.98**	Not Normal	Not Normal	

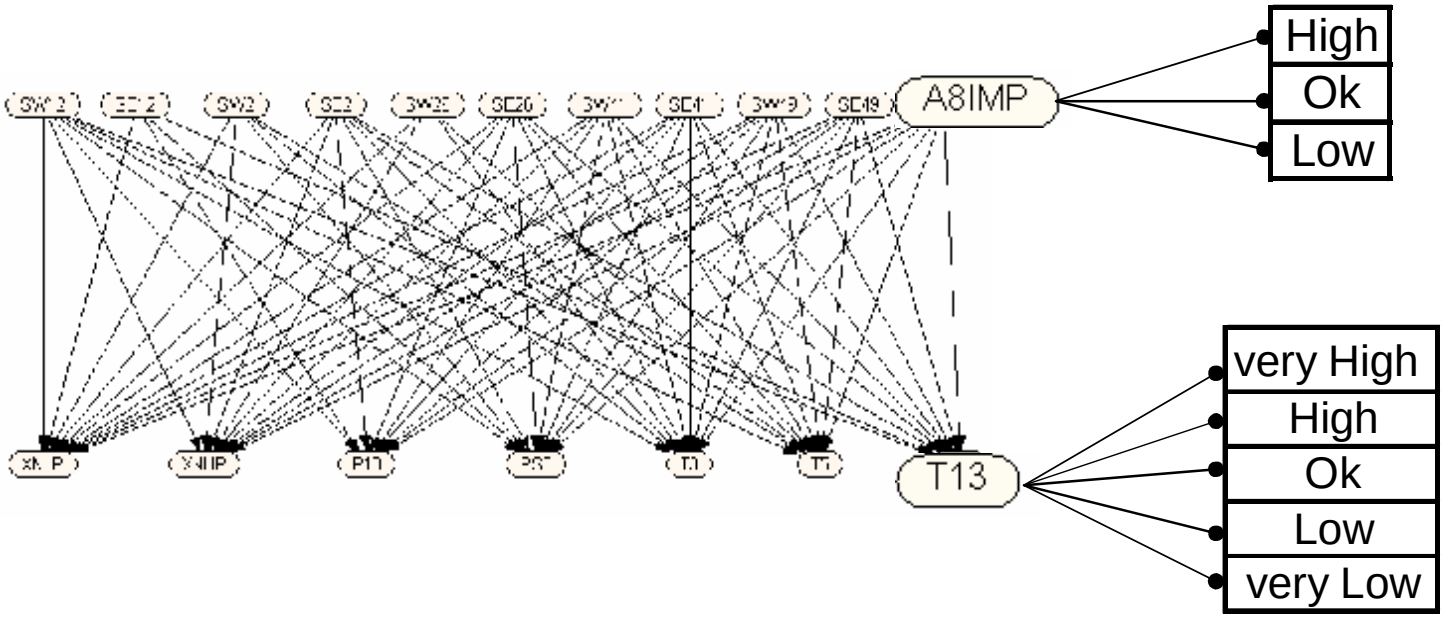
CPT: TIT

States	Normal	Not Normal	n(HPC)	n(HPT)	Nodes
Conditional Probabilities	**0.97**	**0.03**	Normal	Normal	States of parents
	0.16	**0.84**	Normal	Not Normal	
	0.38	**0.62**	Not Normal	Normal	
	0.08	**0.92**	Not Normal	Not Normal	

Structure of the BBN used for GT diagnosis (I)

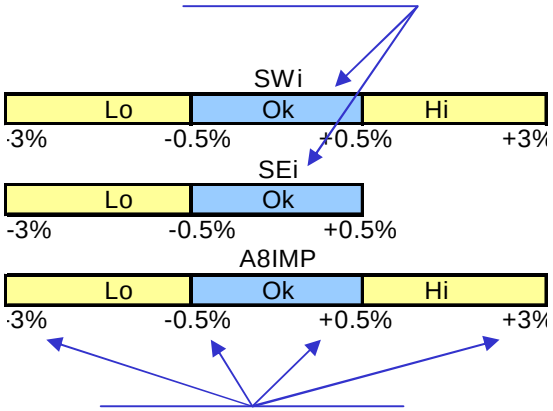


Structure of the BBN used for GT diagnosis (II)



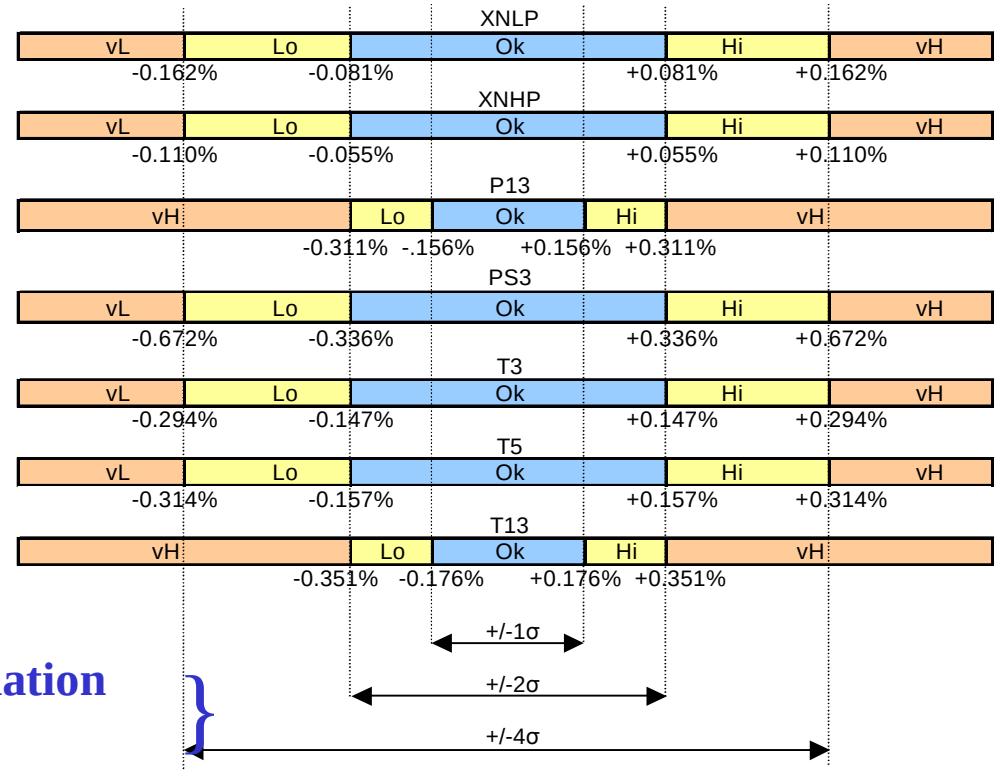
States of nodes of the current BBN

i stands for sections: 12, 2, 26, 41 and 49



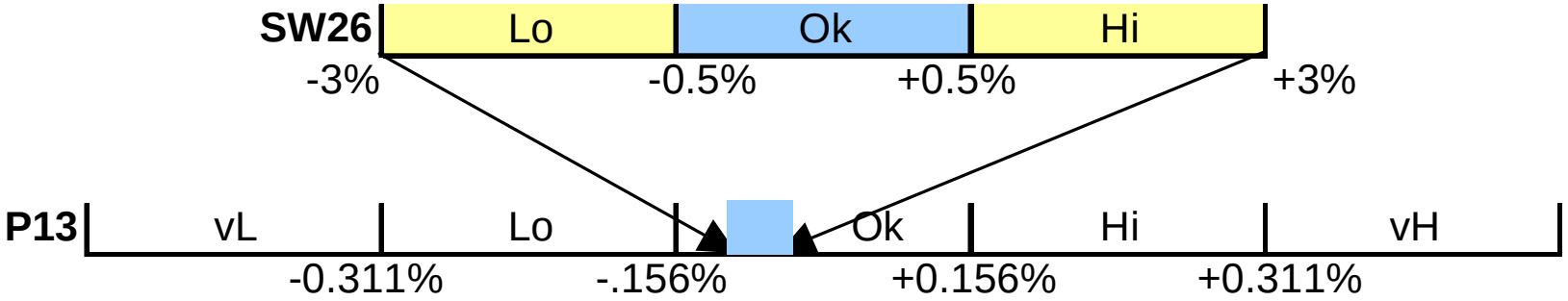
Percentage deviations from nominal value

σ: considered standard deviation of each measurement

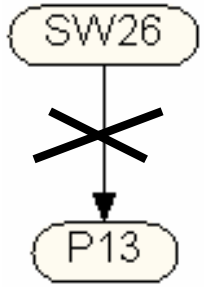


Defining the links among nodes using The Engine Performance Model (EPM)

(Not Linked nodes)

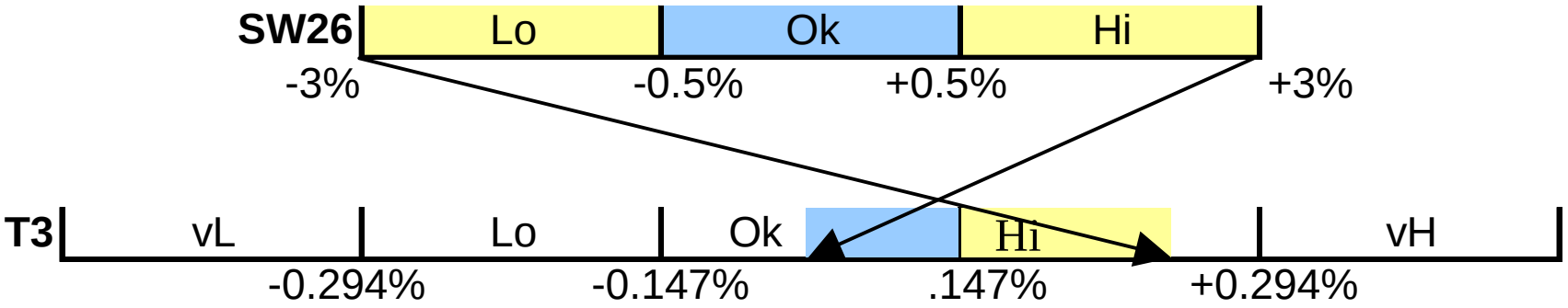


Maximum deviation of fault node ‘SW26’ does not exceed the limits of the state ‘Ok’ of node ‘P13’

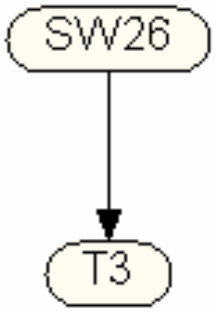


Defining the links among nodes using The Engine Performance Model (EPM)

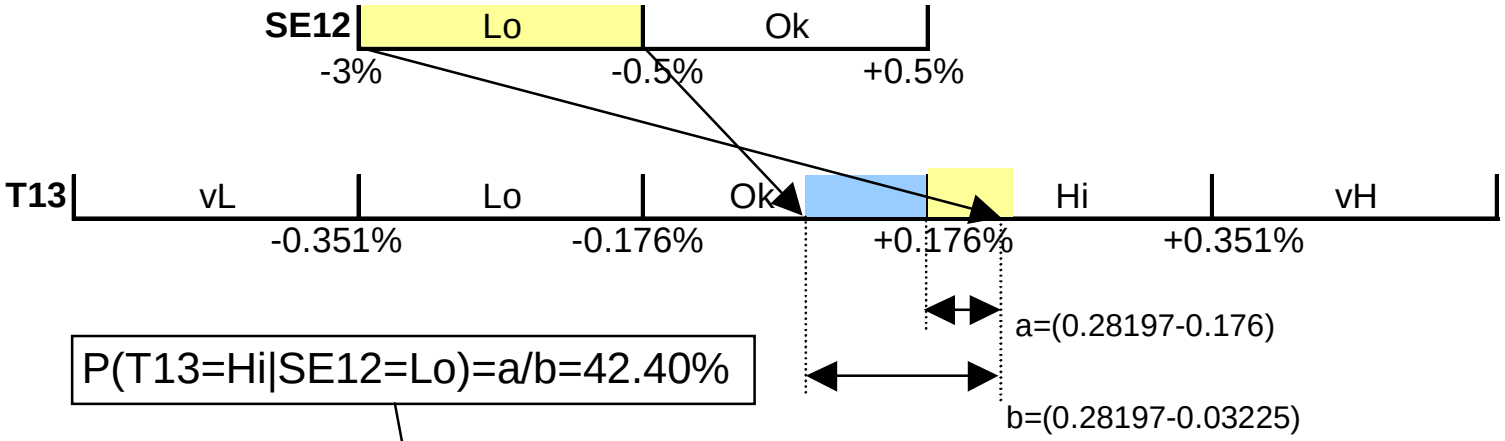
(Linked nodes)



Maximum deviation of fault node 'SW26' exceed the limits of the state 'Ok' of node 'T3'



Defining the CPTs of the nodes using the EPM



Instantiation			T13				
			vL	Lo	Ok	Hi	vH
1	SW12	Lo					
2		Ok					
3		Hi					
4	SE12	Lo					
5		Ok					
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
26	A8IMP	Lo					
27		Ok					
28		Hi					

Generating the Testing patterns (I)

85 fault cases + 1 fault free case considered

+/- (1%, 1.5%, 2%, 2.5%) deviations for each of the 11 fault parameters

↓

Signatures of all fault cases using the EPM

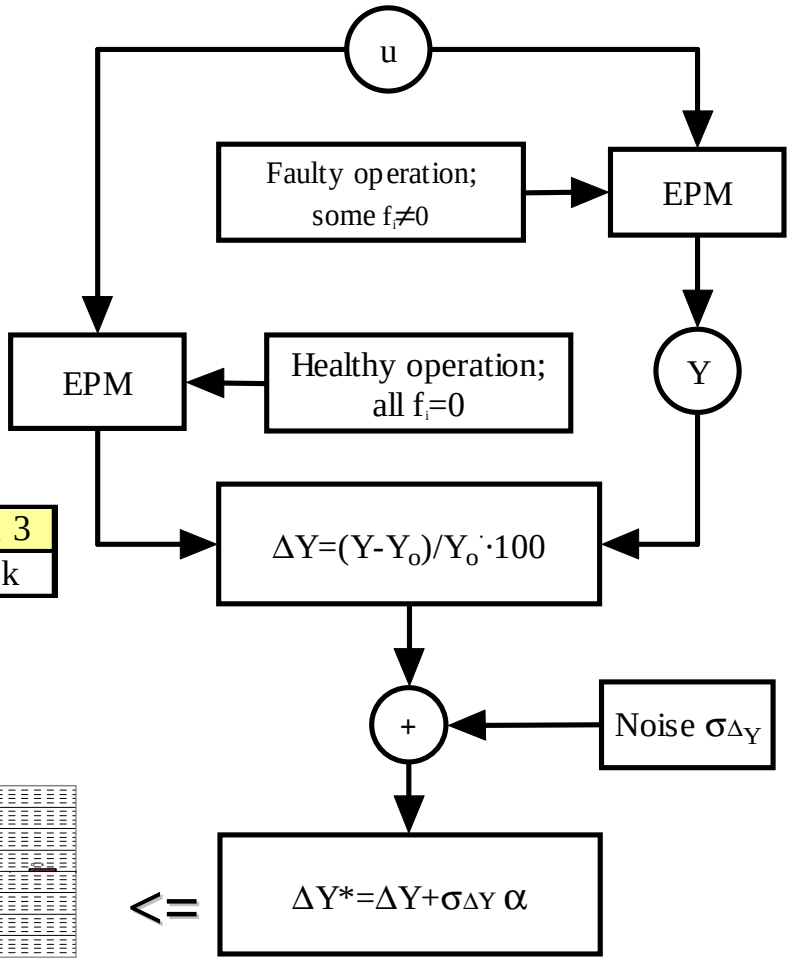
Percentage deviations of the 7 measurements (ΔY_i, i=1, 7)

↓

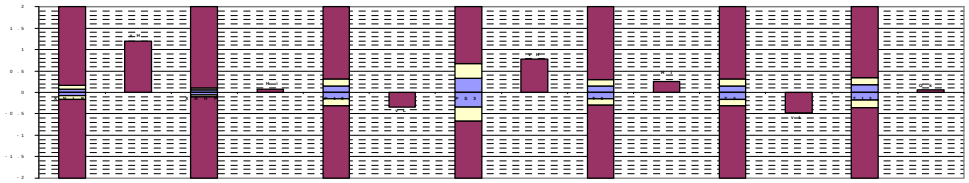
10 'noisy' signatures for each signature of fault

$\Delta Y' = \Delta Y + \sigma(\Delta Y) \cdot \alpha, \quad \alpha \in [0, 1]$

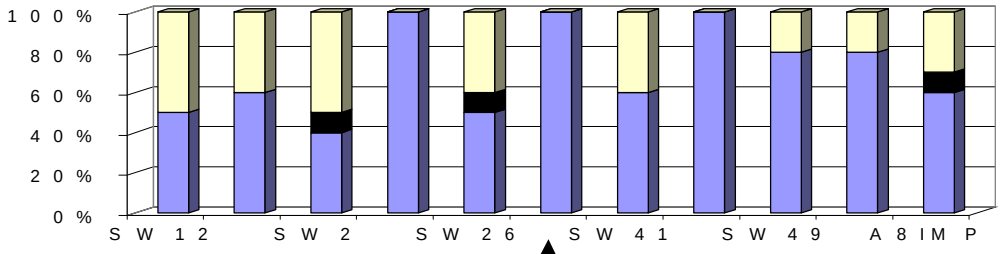
Generating the Testing patterns (II)

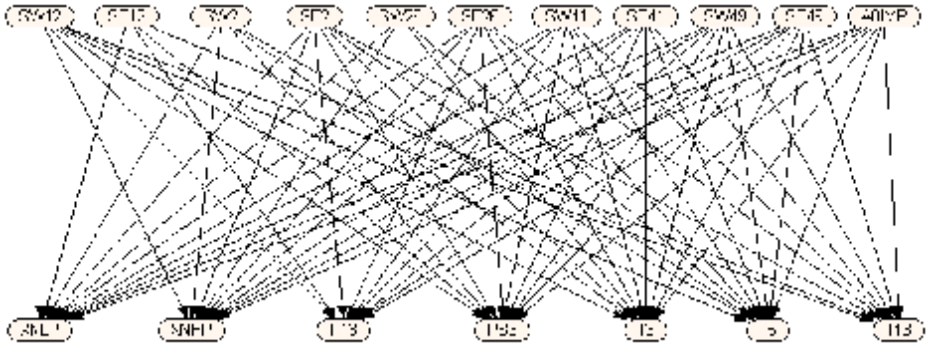


X N L P	X N H P	P 1 3	P S 3	T 3	T 5	T 1 3
v H	H i	v L	v H	H i	v L	O k



Testing the BBN





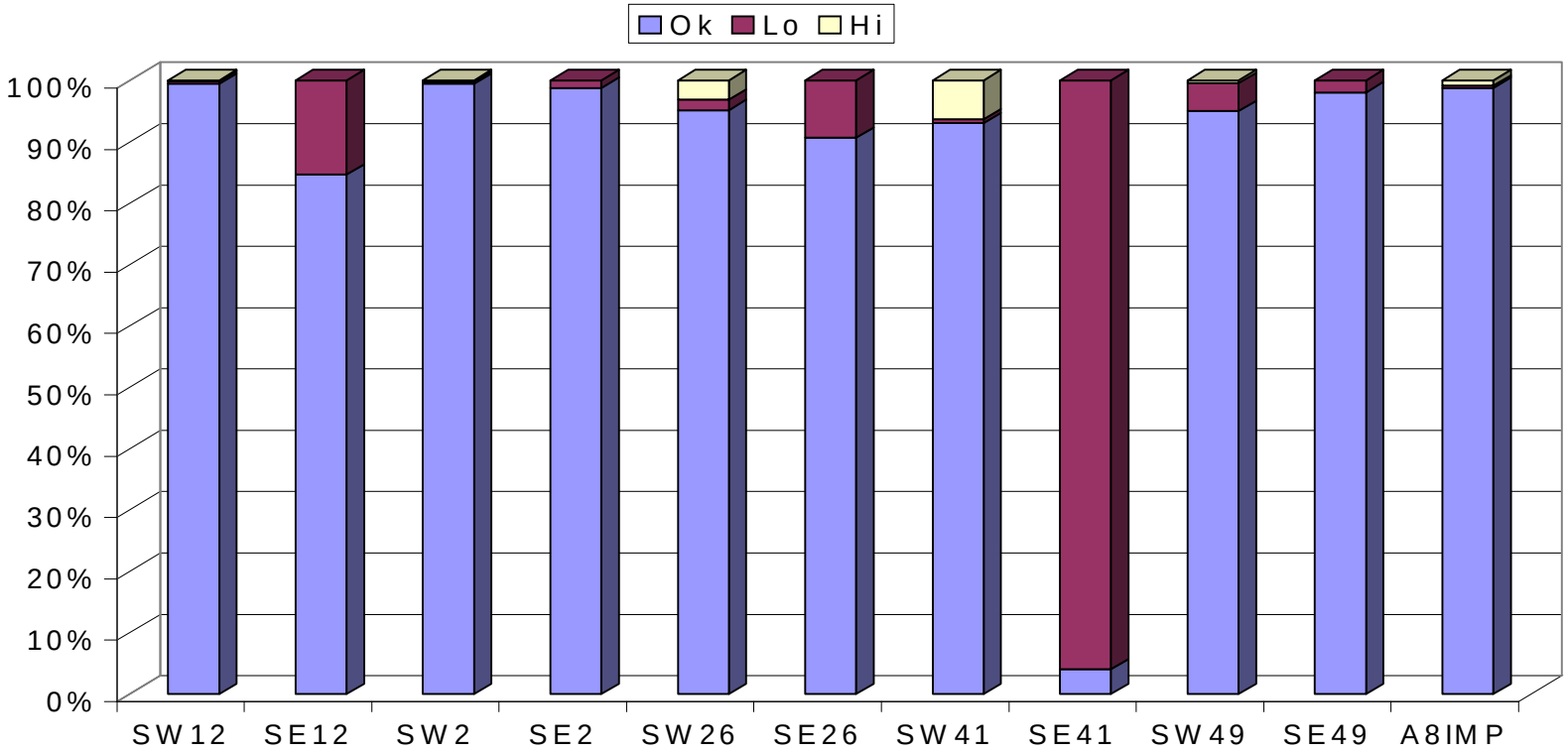
X N L P	X N H P	P 1 3	P S 3	T 3	T 5	T 1 3
v H	H i	v L	v H	H i	v L	O k

Estimated probabilities

BBN Inference

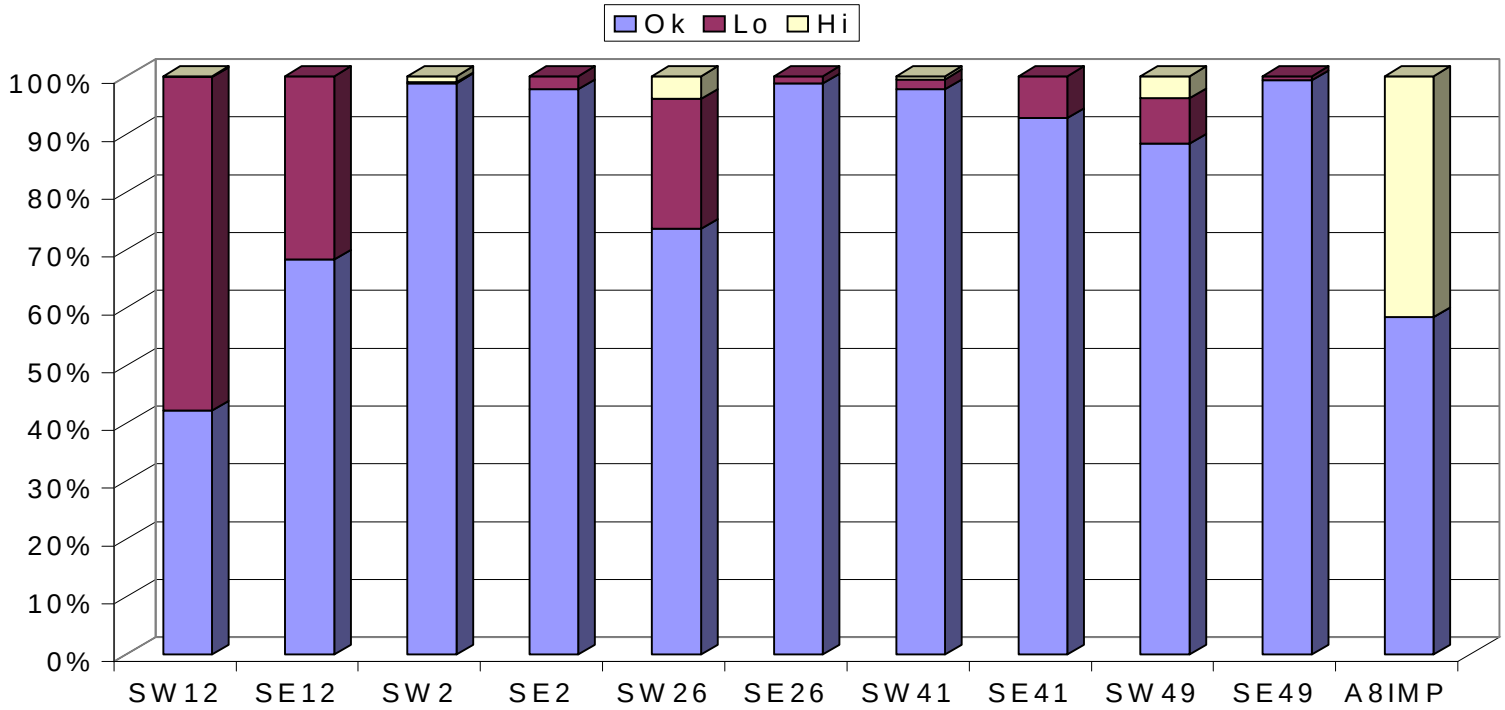
Fault signature

A case of successful detection of fault



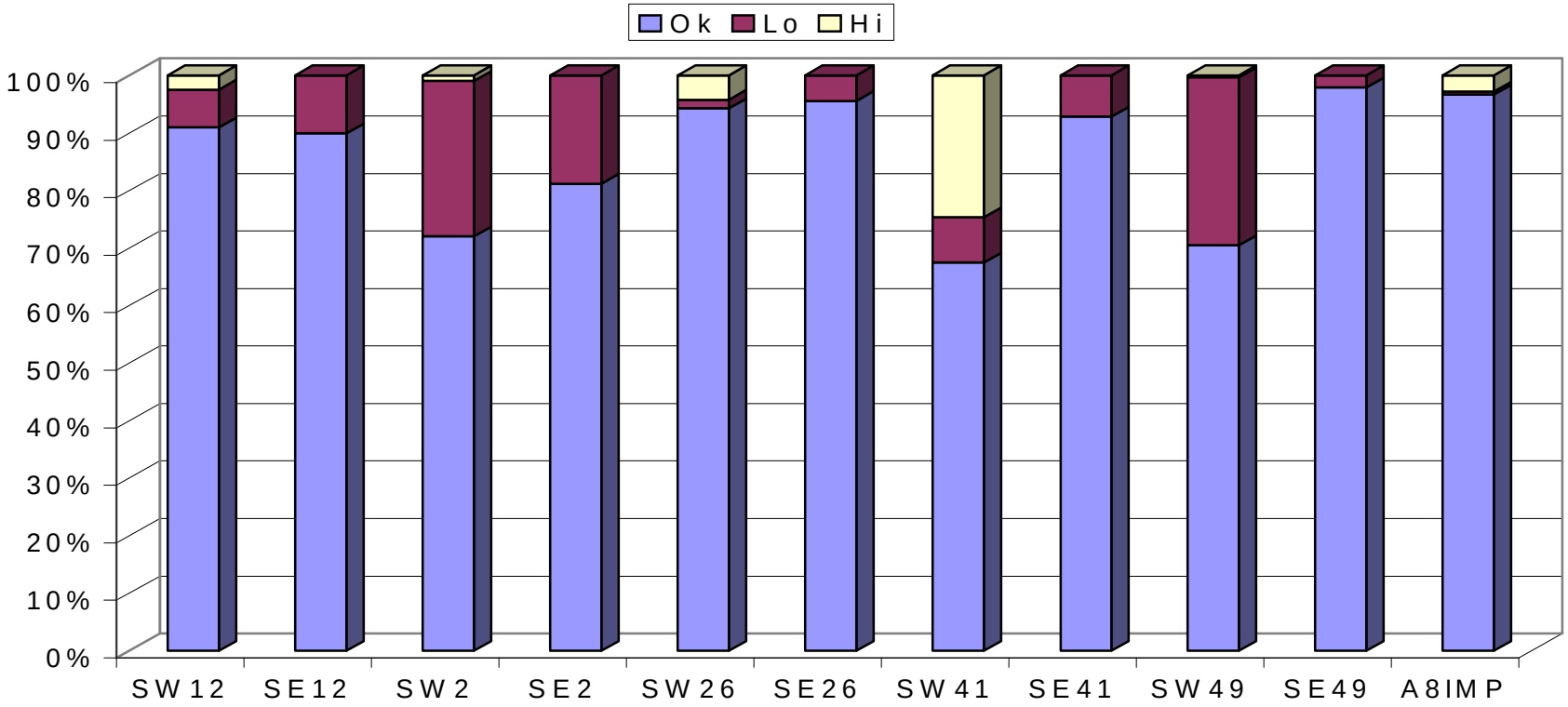
Evidence is the signature of fault: SE41=-2.5%.

A case of unsuccessful detection of fault



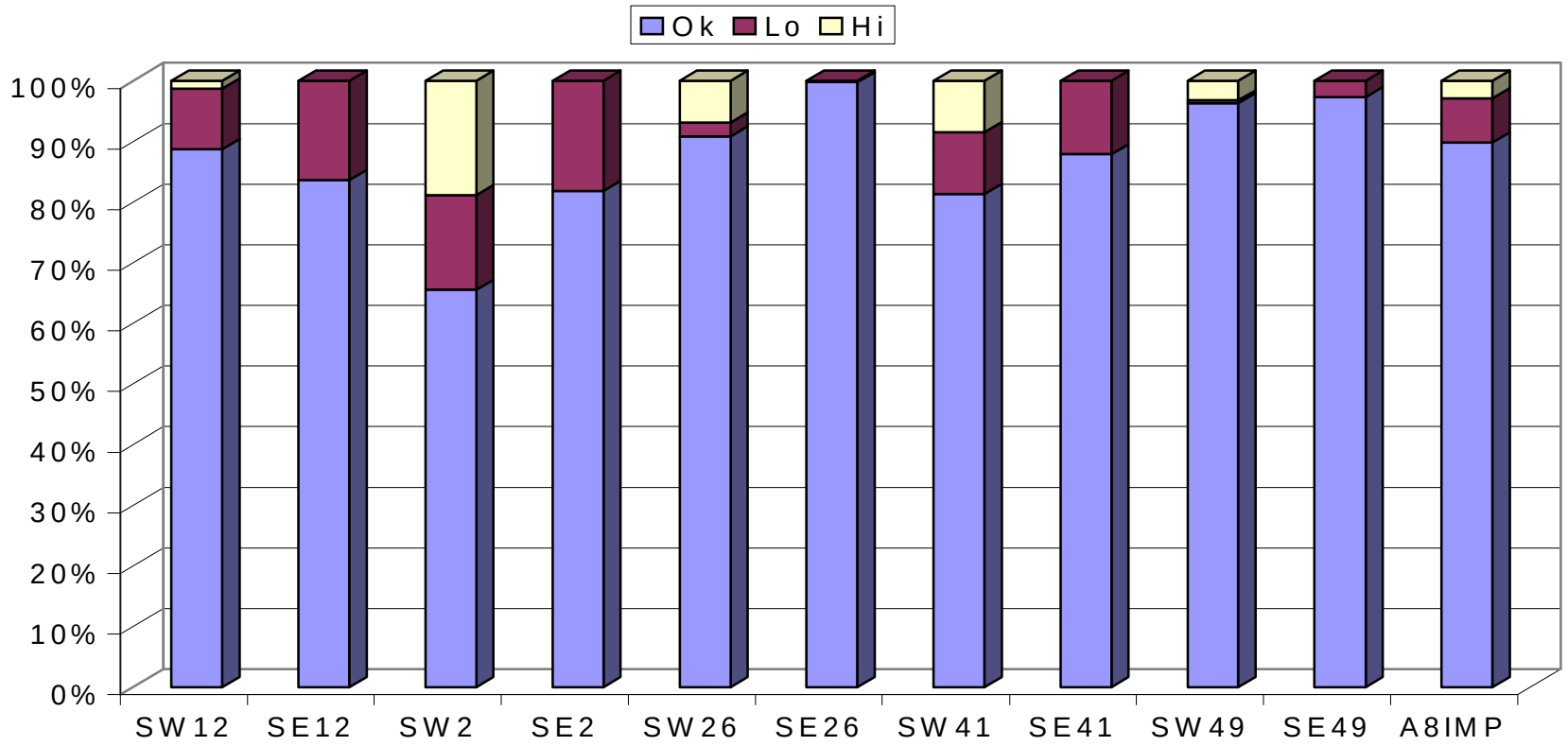
Evidence is the signature of fault: A8IMP=1.5%.

A case of ambiguous detection of fault

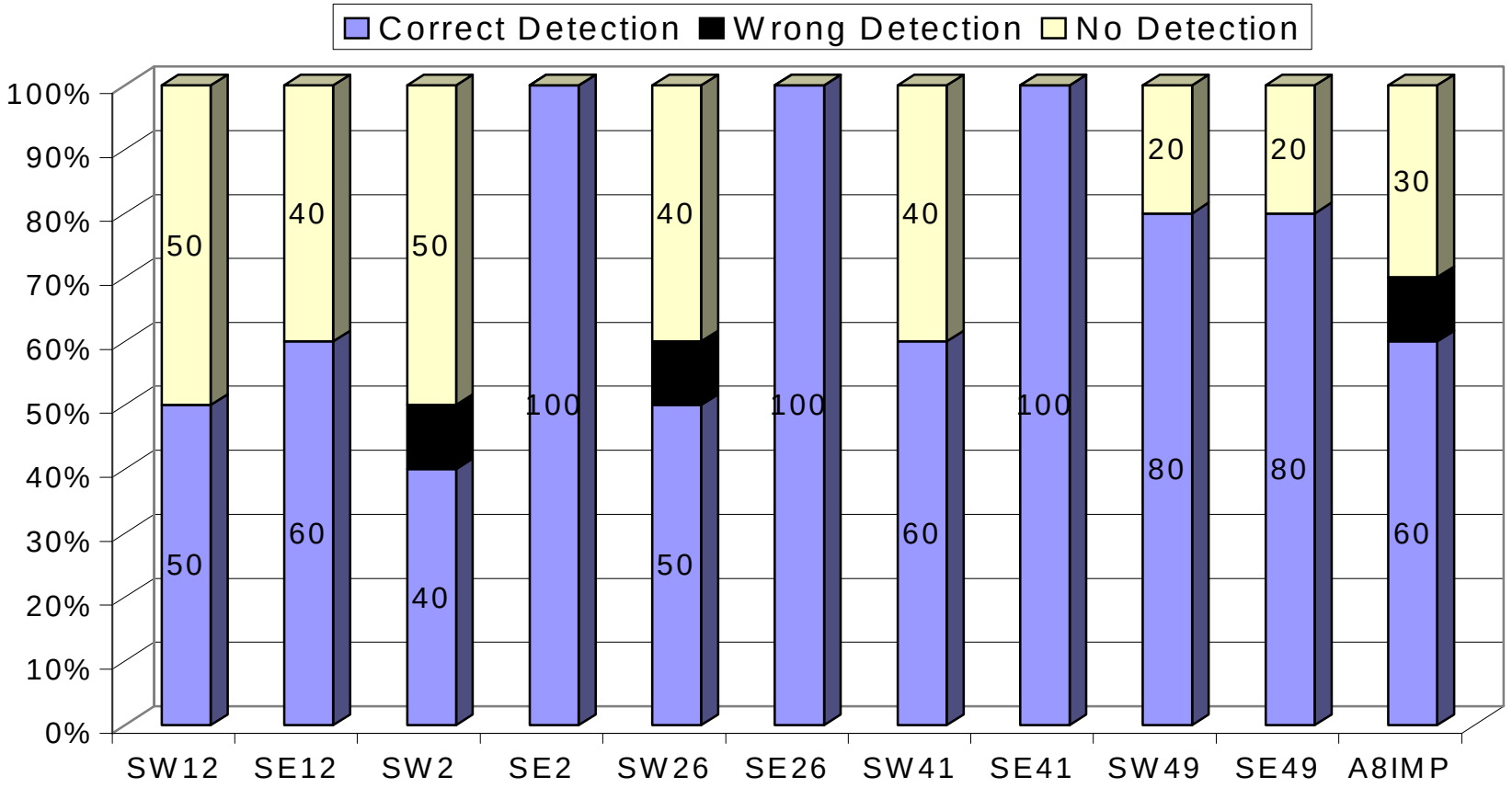


Evidence is the signature of fault: SW2=-2.5%.

Estimated probabilities on the case of a fault free operation of the engine.



Overall diagnostic performance of the BBN



Conclusions - Results

•The general performance of the BBN is promising; although its effectiveness needs improvement BBNs can be built from mathematical models, without the need of hard to find flight data.

•Diagnosis based on the observation of fewer measurements (7) than the considered fault parameters (11)

•Fault are detected with high reliability.

•In most cases of failed detection the BBN did not detect any fault at all (no false alarms).

•It is expected that more accurate approaches for building the BBN will make the network more ‘sensitive’ to the presence of faults.