GO-FLOW

The GO-FLOW and the Bayesian Network in PSA

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In the PSA framework

FTA (Fault Tree Analysis)
GO-FLOW
Bayesian Network(BN)

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GO-FLOW Methodology

1. Success-oriented system reliability analysis methodology.
2. GO-FLOW chart is constructed with standardized operators and signal lines
3. Analysis is performed by one GO-FLOW chart and one computer run.
4. GO-FLOW analysis support system has been developed.

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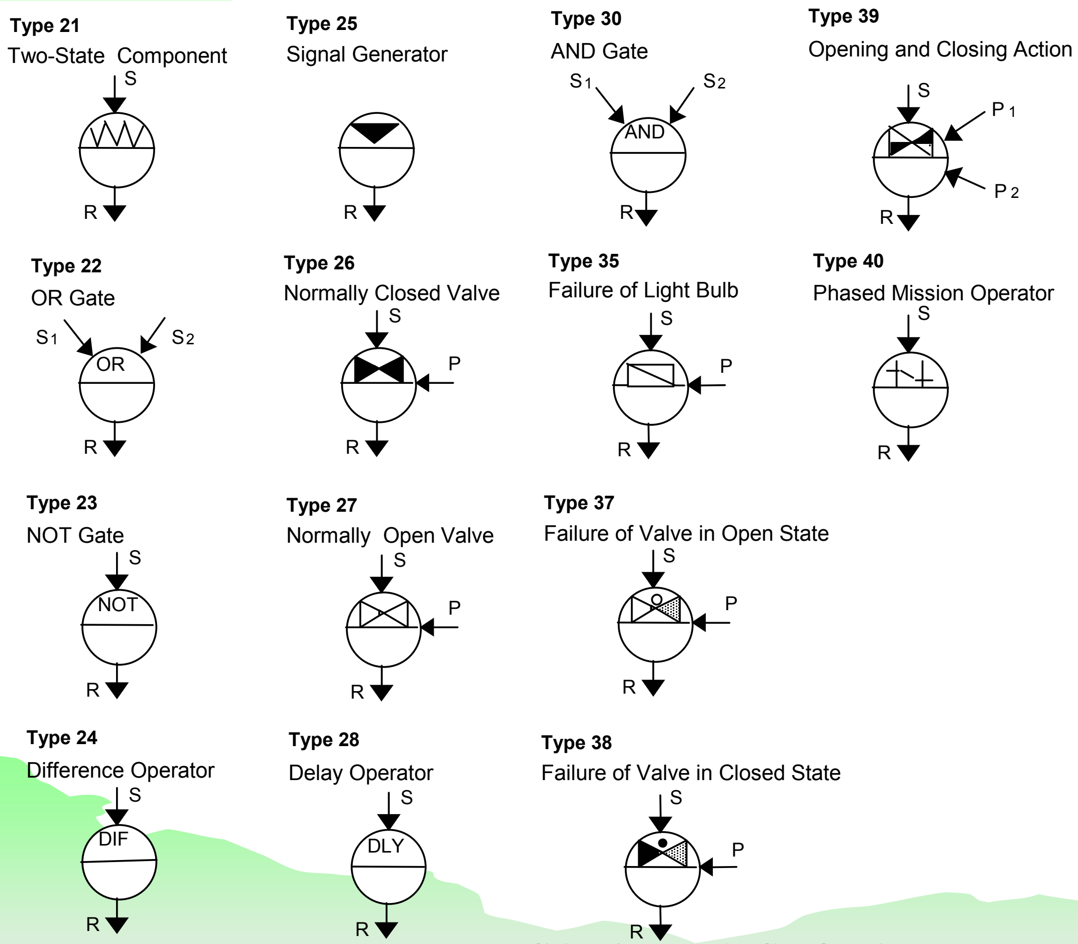
Operators used in the GO-FLOW



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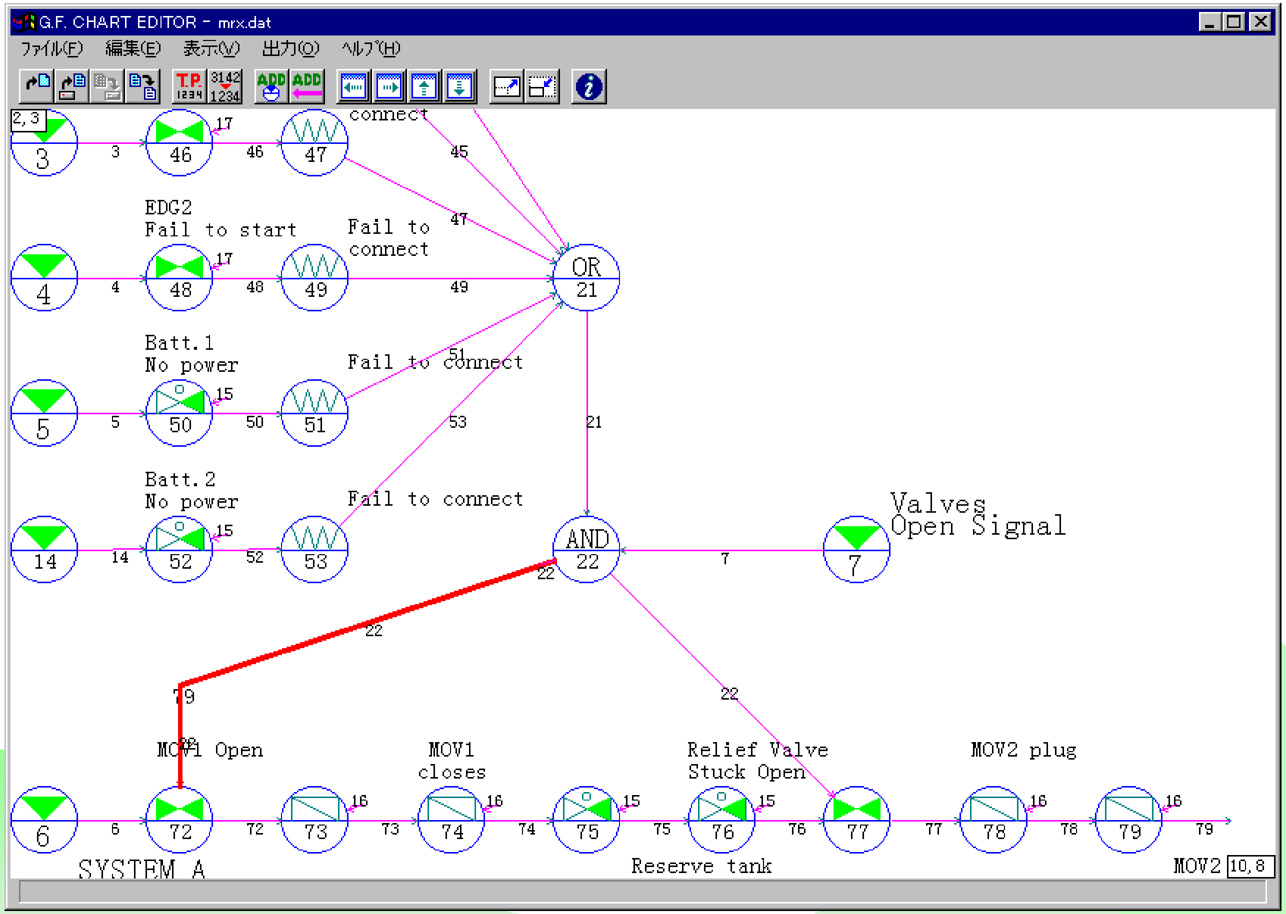

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Analyses related to the GO-FLOW Methodology

Analysis for dynamical system	PSAM3,1996
Safety analysis of fuel cell system for ships	PSAM4,1998
Safety analysis of spent fuel carrier	SRA of J,1998
Analysis of automatic train control system	PSAM4,1998
Operability and hazard analysis of Olefin plant	PSAM4,1998
Development of Safety analysis system	PSA99,1999
Analysis of Human-machine system	PSAM5,2000
A Method to Solve Logical Loops	PSAM5,2000
To treat a continuously maintained activity	PSAM6,2002
More sophisticated improvements to treat a continuously maintained activity	PSAM7,2004
A Self-holding Type Relay System	PSAM8,2006

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Bayesian Network

It is used as a probabilistic method of reasoning under uncertainty knowledge.

Recently, BN has been becoming a popular tool in reliability engineering.

BN is represented by a graphical diagram consists of nodes and directed links.

The BN diagram is similar to the GO-FLOW chart that has operators and signal lines.

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Bayes Theory

$$P_r(\theta_j/HE) = \frac{P_r(\theta_j/H)P_r(E/\theta_j H)}{P_r(E/H)}$$

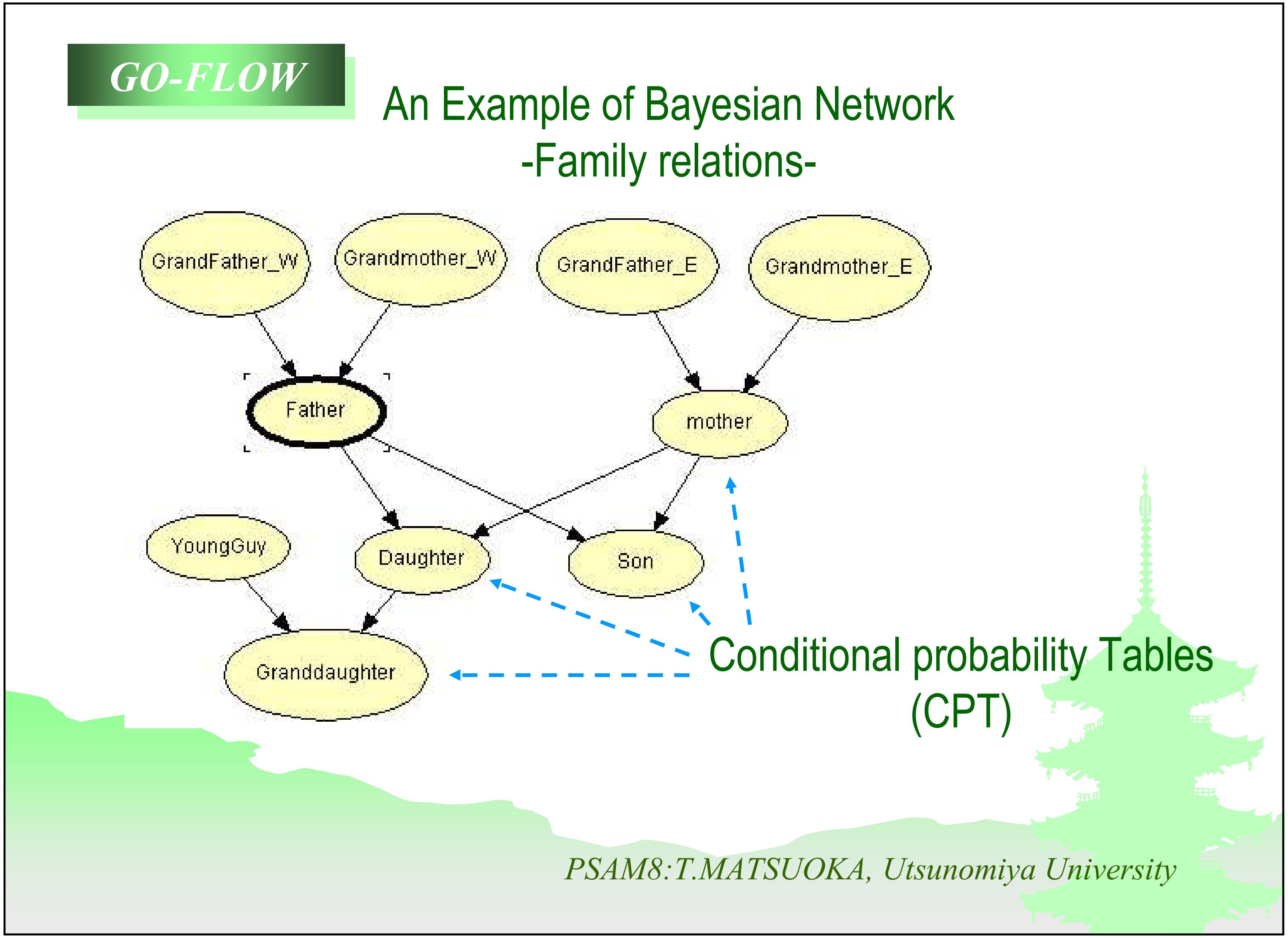
$P_r(\theta_j/H)$; Conditional Probability with prior knowledge H

θ_j ; Some variable

H ;prior knowledge

E ;New evidence

$P_r(\theta_j/HE)$; Posterior Distribution with H and E


GO-FLOW
An Example of Bayesian Network
-Family relations-
GrandFather_W
Grandmother_W
GrandFather_E
Grandmother_E
Father
mother
YoungGuy
Daughter
Son
Granddaughter
Conditional probability Tables
(CPT)
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Examples of CPT

Grandfather

aa	0.3333
aA	0.3333
AA	0.3333

Gene: A, a

Son, Daughter (law of inheritance)

Mother	aa			aA			AA		
Father	aa	aA	AA	aa	aA	AA	aa	aA	AA
aa	1	0.5	0	0.5	0.25	0	0	0	0
aA	0	0.5	1	0.5	0.5	0.5	1	0.5	0
AA	0	0	0	0	0.25	0.5	0	0.5	1

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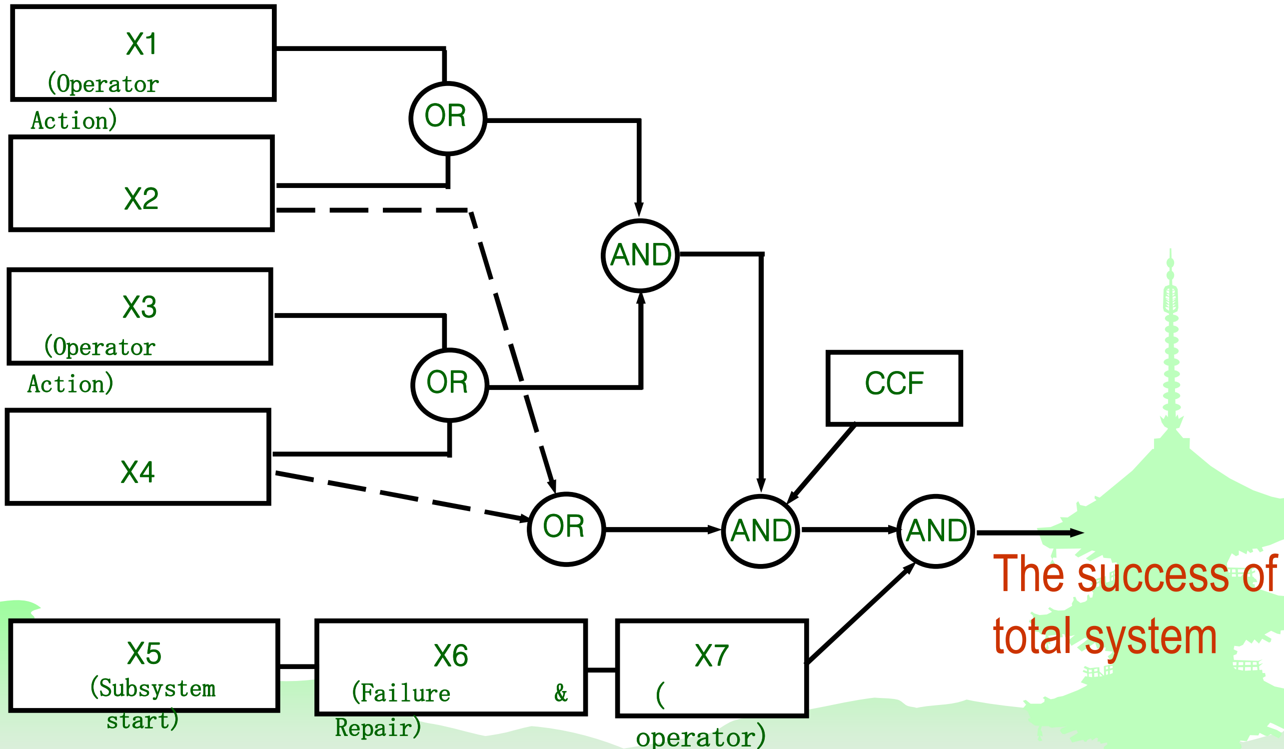
A SYSTEM FOR ANALYSES

A simple but a little complicated hypothetical system



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Logic of the sample system

X2 and X4 are some mechanical or electrical components.
Operator action (X1) plays an alternative role for the function of X2, if some failure occurs to X2.
(The same relation is given between X3 and X4.)

Both X2 and X4 function is required. → AND combination.

At least one hardware component(X2 or X4) must be in sound condition.
→ X2 and X4 is combined by OR combination.

CCF :Contribution from common cause failure of X2 and X4

Remaining part of the system is represented by sub-system X5.
X6 :Sub-system failure and repair action.
X7: Operational error.

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Table 1: Time steps

Time step	Meaning	Comments
1	Initial time	Sub-system starts to operate
2	10 hours	
3	30 hours	
4	100 hours	
5	Repair action	Failure is recovered and becomes as new
6	Additional 30 hours	

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Table 2: Failure data

Component (Event)	Failure data	Failure probability at time step 4	Comments
X1	λ=1.054x10-3/h	0.1	
X2	λ=3.567x10-3/h	0.3	
X3	λ=1.054x10-3/h	0.1	
X4	λ=3.567x10-3/h	0.3	
X5	0.1	0.1	Successful start is 0.9
X6	λ=3.567x10-3/h,	0.3	Failure is repaired at time step 5
X7	λ=1.0x10-5/h	0.001	
CCF	λ=1.0x10-4/h	0.01	

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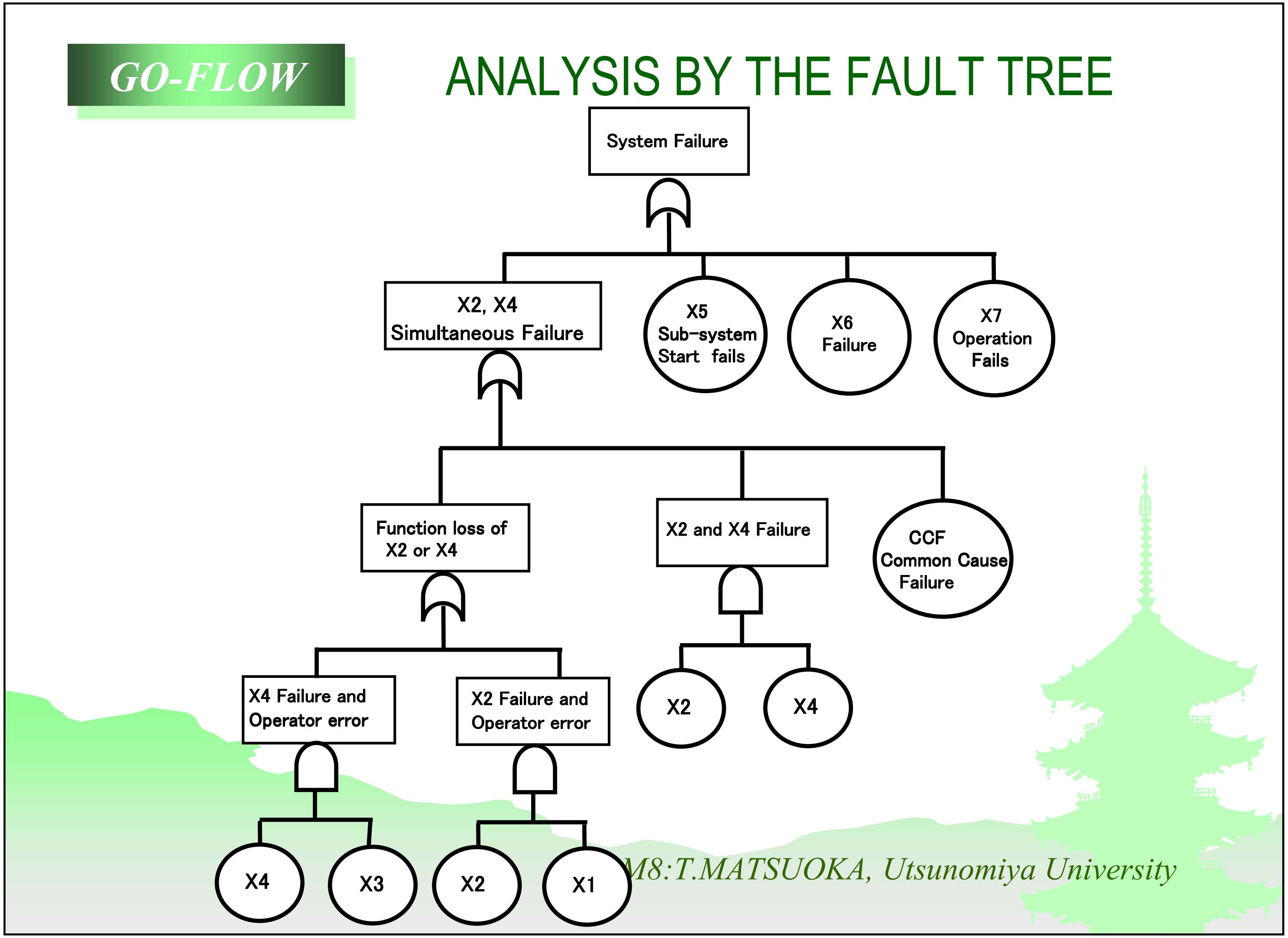
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ANALYSIS BY THE FAULT TREE
System Failure
X2, X4
Simultaneous Failure
X5
Sub-system
Start fails
X6
Failure
X7
Operation
Fails
Function loss of
X2 or X4
X2 and X4 Failure
CCF
Common Cause
Failure
X4 Failure and
Operator error
X2 Failure and
Operator error
X2
X4
X4
X3
X2
X1
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$$System\ failure = X1 \cdot X2 + X3 \cdot X4 + X2 \cdot X4 + CCF + X5 + X6 + X7$$

The system failure probability is calculated at 0.4592

Failure and repair of sub-system(X6) shows prominent values.

RRW=2.02,

RAW=2.18,

Birnbaum=4.40,

F-V=0.505,

Criticality=0.505.

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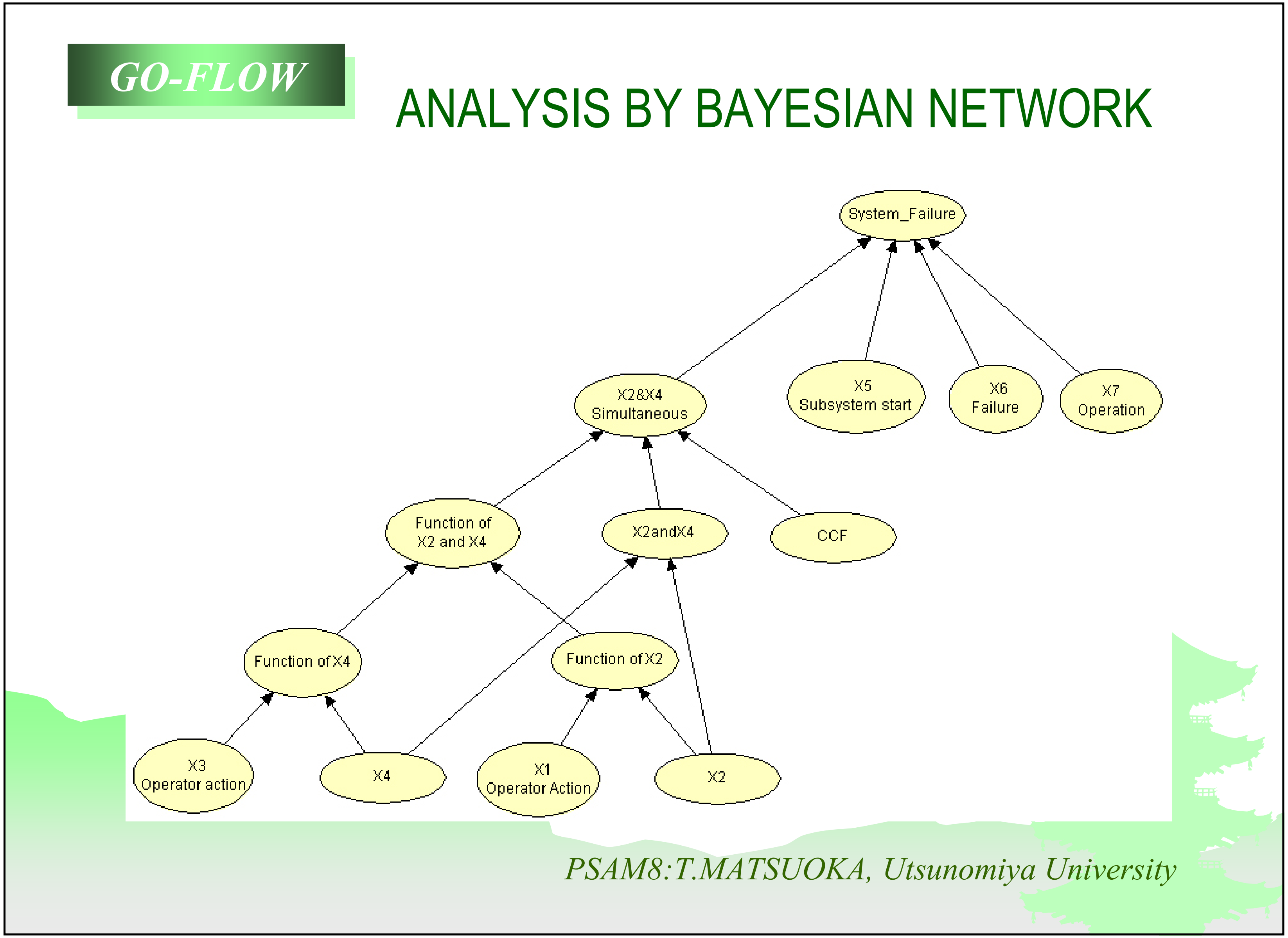
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ANALYSIS BY BAYESIAN NETWORK
System_Failure
X2&X4
Simultaneous
X5
Subsystem start
X6
Failure
X7
Operation
Function of
X2 and X4
X2andX4
CCF
Function of X4
Function of X2
X3
Operator action
X4
X1
Operator Action
X2
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Examples of CPT

X2

X4andX3 | X2andX5 | X2 | X4 | X5 | X3 | XCM

True	0.7
Failure	0.3

X4 or X2

X4	True		Failure	
X2	True	Failure	True	Failure
True	1	1	1	0
Failure	0	0	0	1

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Exactly the same value is obtained for the system failure.
The measures of importance are also easily calculated in BN.

The posterior probability of any given variables.

A new evidence: X6=0.15

=>System failure: 0.2817

A new evidence: a top event(system failure itself).

=> the possible explanations of an exhibited system failure.

This is a kind of diagnostic analysis.

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Common Cause Failure

$$X2 = T_2 + Ind_2 + CCF, \qquad X4 = T_4 + Ind_4 + CCF \quad (7)$$

$$(X2 + X4)(True) = T_2 \cdot T_4 + T_2 \cdot Ind_4 + T_4 \cdot Ind_2,$$

$$(X2 + X4)(Failure) = Ind_2 \cdot Ind_4 + CCF$$

CPT for X2 and X4 combination

X2	TRUE			Indpendent			CCF		
X4	TRUE	Ind	CCF	TRUE	Ind	CCF	TRUE	Ind	CCF
TRUE	1	1	0	1	0	0	0	0	0
Failure	0	0	0	0	1	0	0	0	1

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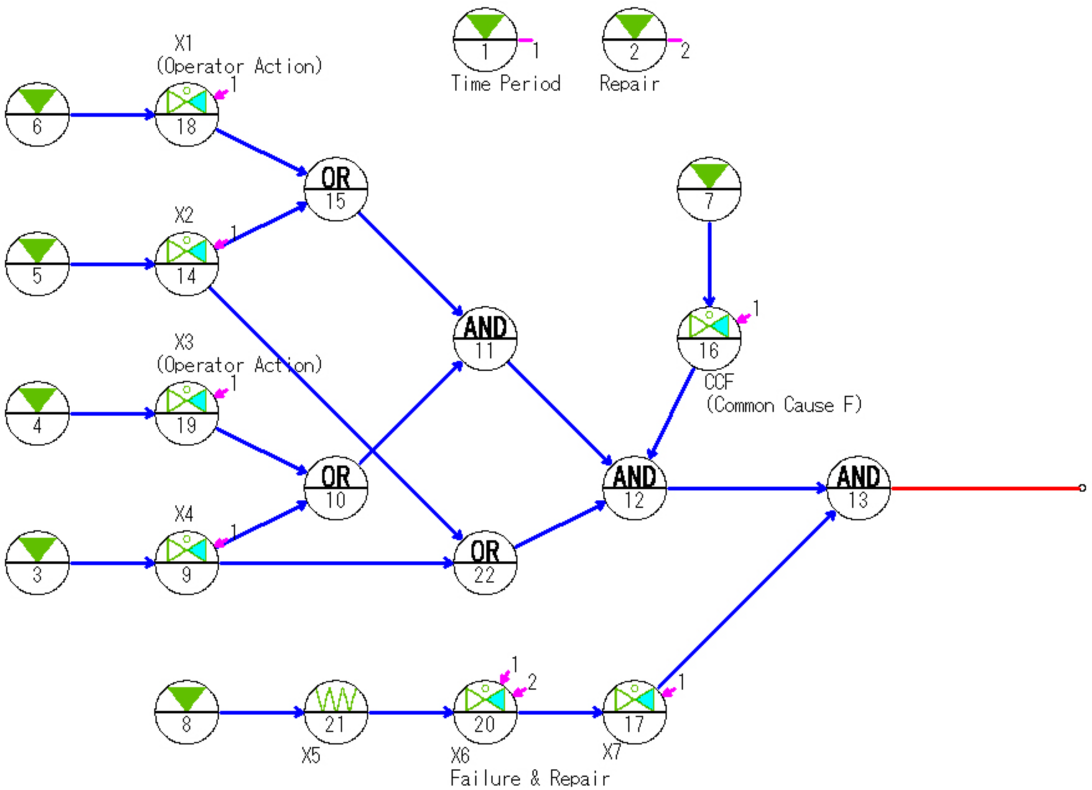
Analysis by the GO-FLOW



Configuration of GO-FLOW chart is well corresponds to the system block diagram shown in figure 1.

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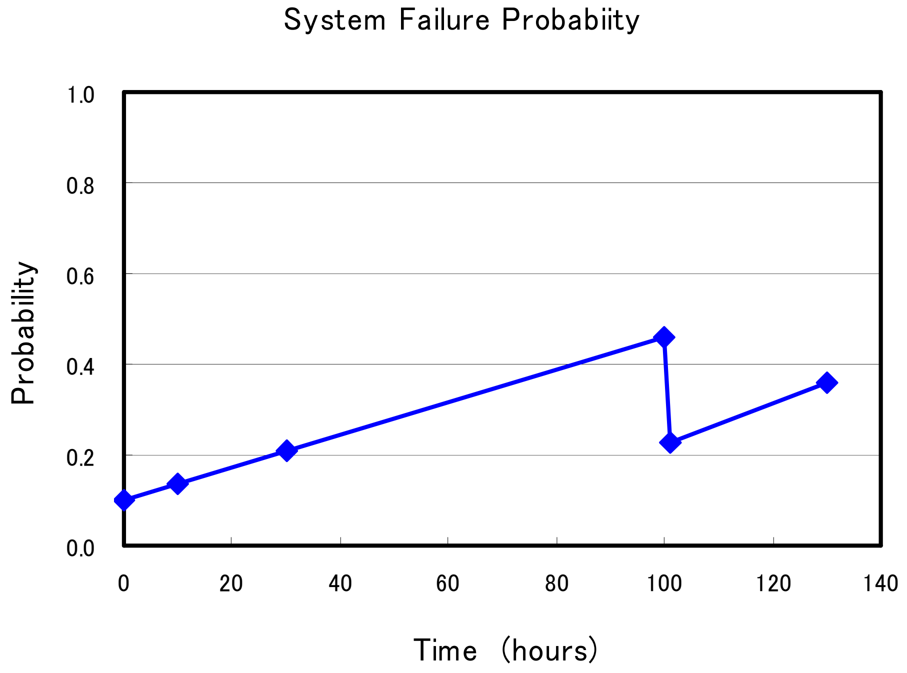
Figure 5. Analysis result by the GO-FLOW.



System failure probability increase with time till 100 hours, and effects of repair is seen at 100 hours

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CONCLUSIONS

- The same example has been analyzed by the GO-FLOW, BN, and FTA.
- FTA is very familiar to almost all the system engineers, and is a convenient tool for a simple system, but it requires special skills for the modeling of a complex system or complicated condition.
- A limited function is provided to the FTA, because only logical OR and AND gates are used, and events are binary events; success or failure, and only a static system can be analyzed.

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CONCLUSIONS(2)

- BN can easily model a complicated situation, such as component's state requires multiple state, and has logical combination which can be flexibly defined.
- BN gives us the posterior probability of each event in case definite values are given to specific components. So, BN is useful for the decision making with the uncertain data, or after getting a new evidence.
- BN has some difficulty to treat the common cause failure, and can handle only a static system.

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CONCLUSIONS(3)

- The GO-FLOW is strong for modeling dynamical system behavior and can easily obtain time-dependent system reliability.
- The GO-FLOW provides many kinds of operators, by which complicated system operation is modeled with conventional procedure.
- The GO-FLOW can rigorously treat the common cause failure.

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CONCLUSIONS(4)

- The GO-FLOW and BN have different features, and both tools give us straightforward procedure for modeling complex systems.
- They are properly used depending on the analysis purposes in PSA.

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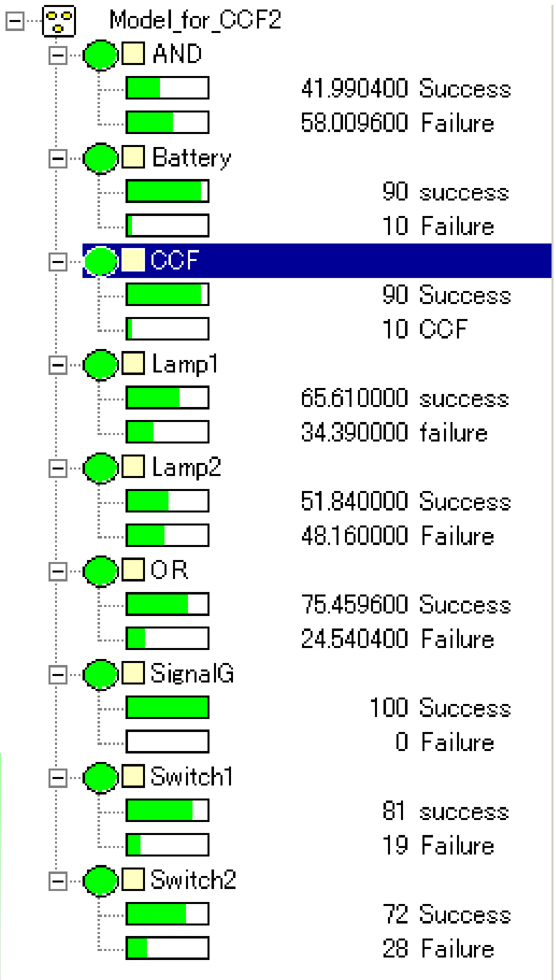
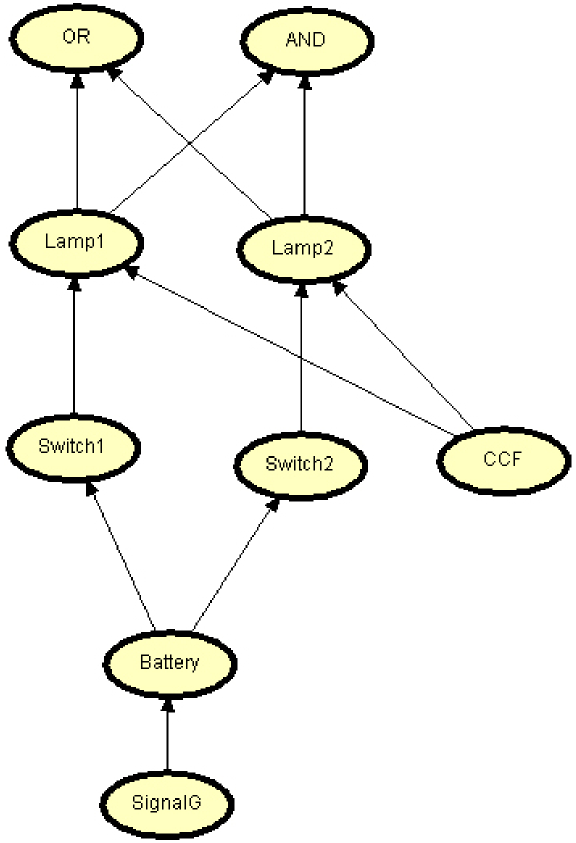
Modeling idea for Common Cause Failure





PSA

Switch2 | Switch1 | CCF | Lamp2 | Lamp1

Switch2	Success		Failure	
CCF	Success	CCF	Success	CCF
Success	0.8	0	0	0
Failure	0.2	1	1	1