TIMED-FAULT TREE GENERATION FROM DYNAMIC FLOWGRAPH METHOD

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Motivations

- Many new and old NPPs are intended to *upgrade or replace the aging control systems* from analogue to digital technology
- *Currently limited guidance and consensus* on reliability modelling of digital system
- *Integrated analysis* of Software and Hardware systems
- *Incorporation of Dynamic Models* into existing conventional PRA models

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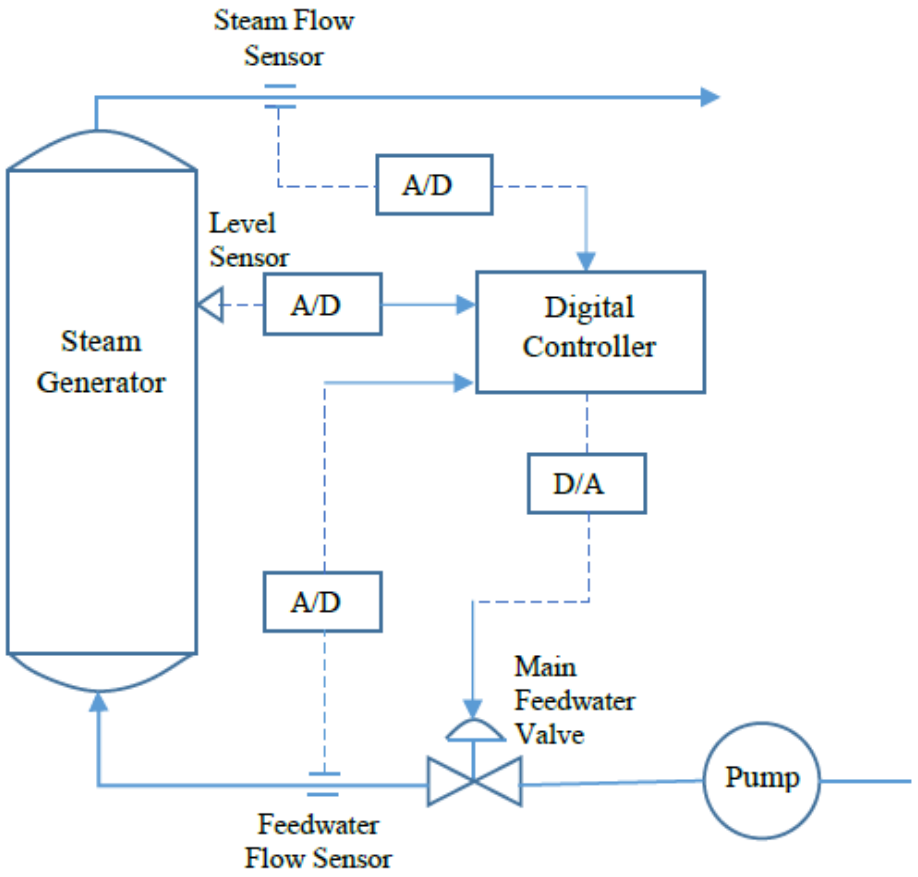
System Description

System Components:

1. U-tube Steam Generator
2. Feedwater Pump
3. Digital Controller
4. Main Feedwater Valve
5. Level Sensor
6. Feedwater Flow sensor
7. Steam Flow sensor
8. A/D converter
9. D/A converter



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System Boundary Conditions

- A *Non-repairable* system

Physical Consistency:

- A process variable with different state cannot occur at the same time step (e.g., *valve open AND valve closed @t= -1 cannot happen*)

Dynamic Consistency:

- A process variable can change its states only by a certain amount in a single time-step (e.g., *SG level cannot change from 0% to 90% in a single time step*)

Dynamic Flowgraph Method?

- The *IAEA and the USNRC* study ranked DFM an Markov-CCMT as the *top two* with most viable, positive features and least uncertain features for reliability analysis of digital systems *[NUREG-6901]*
- DFM can provide the multi-state and time-dependent *equivalent of both FTA and FMEA*
- A system approach to *Integrate hardware and software analysis*

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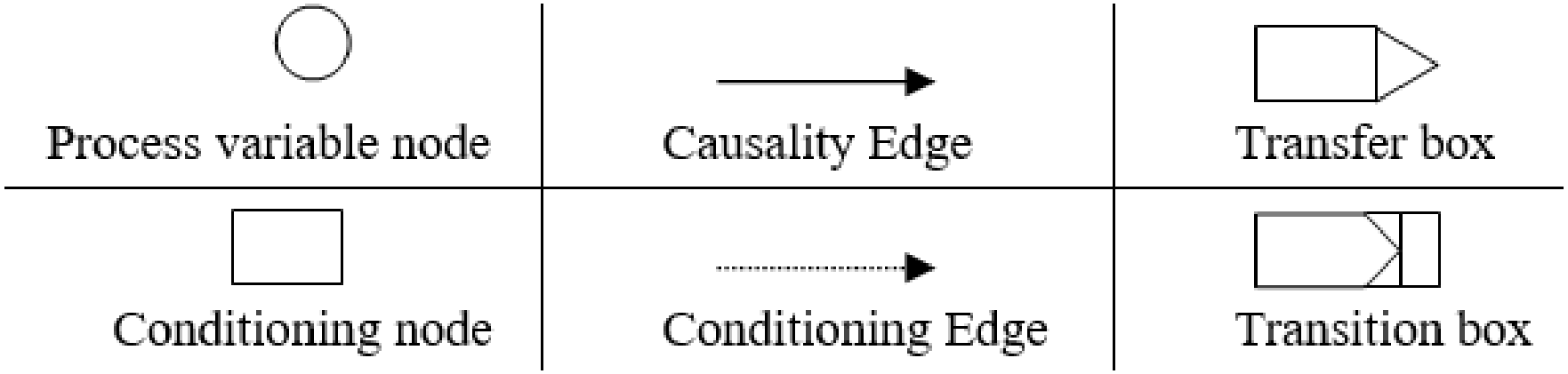
Dynamic Flowgraph Method

- A Multi-Valued Logic Model (*unlike binary states-0,1*) and non-coherent
- Expresses the logical and dynamic (*time-dependent*) behavior of a system
- Dynamic behaviors are represented as a *series of discrete state transitions*
- When did the failure event occurred? At what magnitude?

DFM modelling elements



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DFM Modelling Approach

A two step Process:

1. Model construction (*DYMONDA*)
2. Model Analysis (*Inductive or Deductive*) – the latter is used in this paper.

Process Variable Discretization

- All Process Variables are discretized into arbitrary number of states *(analyst choice)*

SG Level Sensor state

State	Description
-1	Failed Low
0	Normal
+1	Failed High

SG Level

State	Description
0	0% – 25%
1	25% - 50%
2	50% – 60%
3	60% – 70%
4	70% – 80%
5	80% – 85%
6	85% – 90%
7	90% – 100%

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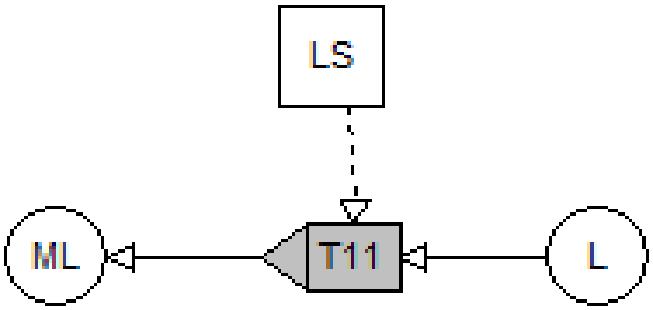
Decision Table Development



Decision table of T11

No.	LS	L	ML
1.	1	0	0
2.	1	1	1
3.	1	2	2
4.	1	3	3
5.	1	4	4
6.	1	5	5
7.	1	6	6
8.	1	7	7
9.	-1	*	0
10.	+1	*	7

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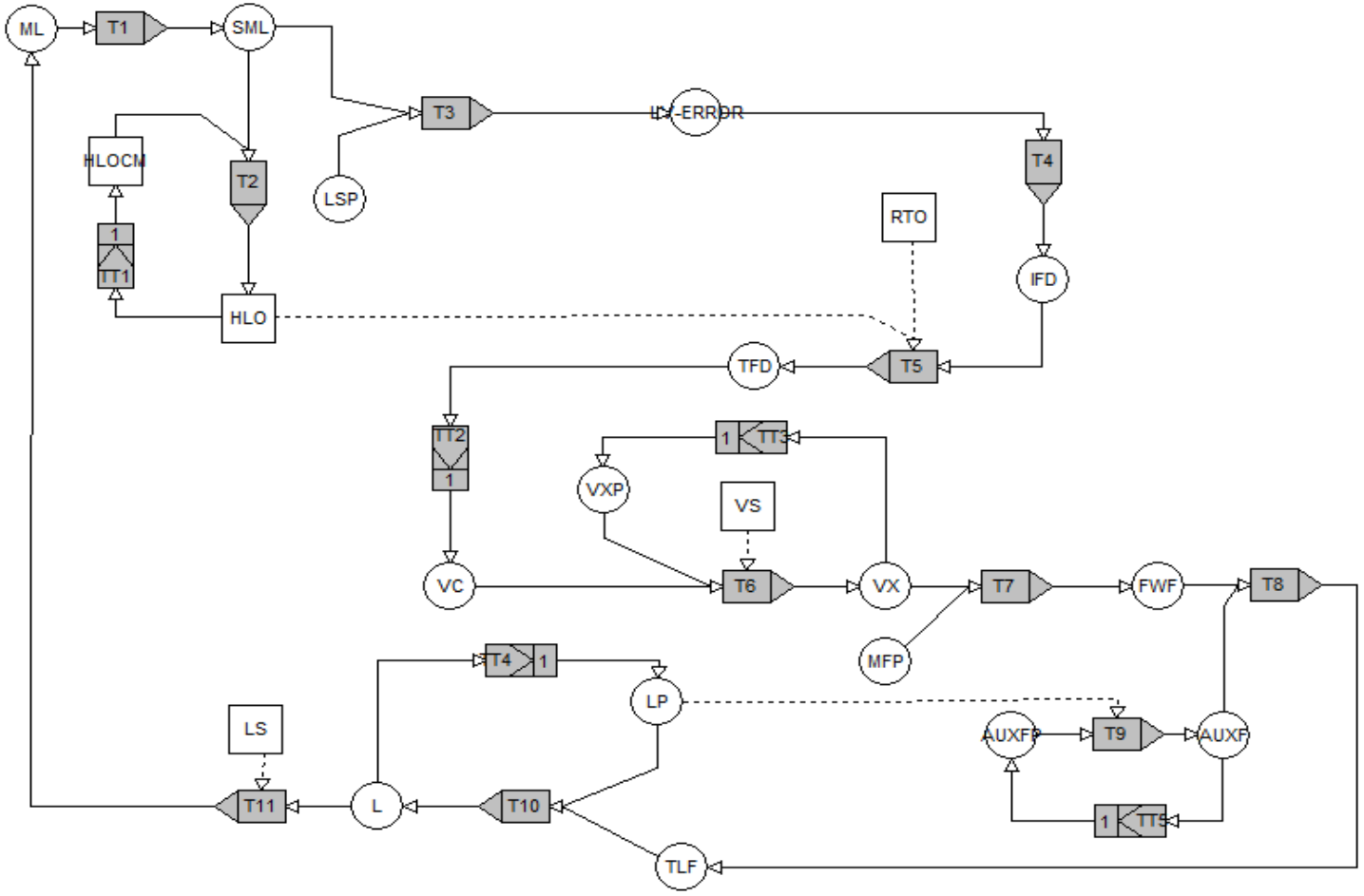
DFM model of a 1-element SGLC system



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Prime Implicants

- *Implicants:* Analogous to Cut-sets in FTA
- *Prime Implicants:* Analogous to Minimal cut-set in FTA, but it is *time-stamped* *(e.g., A_i@t=-1 : A variable "A" have state "i" at time "t=-1")*
- *Base:* Set of Prime implicants logically equivalent to the TOP function
- *Complete Base of Prime Implicants:* Identification by the *Method of Generalized Consensus*

Prime Implicants for SG Overflow

#	Prime Implicants	Time	Logic
1.	SG level was between 90% to 100%	@t= -1	
2.	Main feed pump is normal	@t=0	AND
	Main feed valve stucked high	@t=0	AND
	SG level was between 85% to 90%	@t= -1	
3.	Main feed pump is normal	@t=0	AND
	Main feed valve is normal	@t=0	AND
	Reactor trip override signal was inactive	@t= -1	AND
	High level override signal was inactive	@t= -1	AND
	SG level sensor stucked low	@t= -1	AND
	SG level was between 85% to 90%	@t= -1	AND
	Main feed valve was open between 60% to 80%	@t= -1	

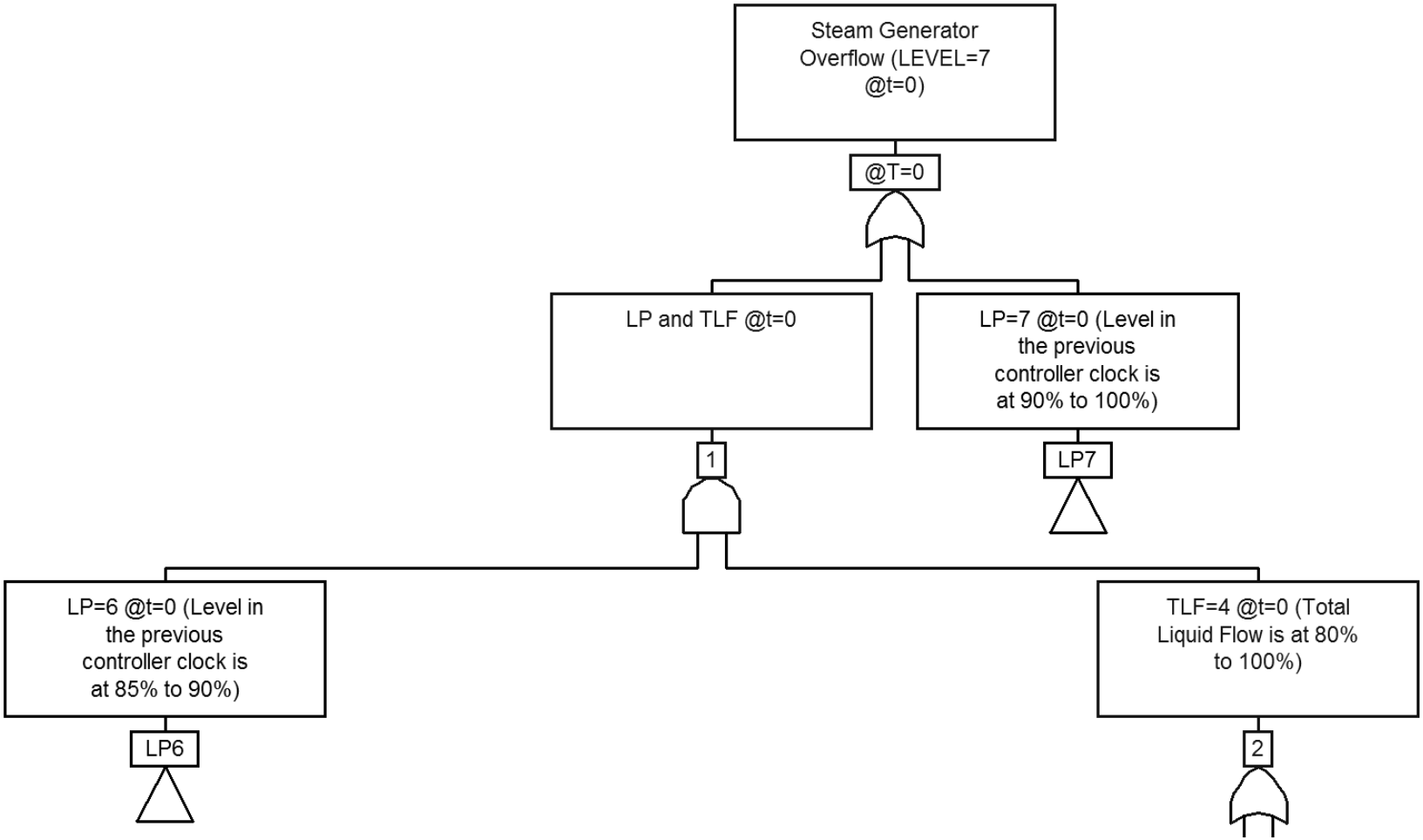
Timed-Fault Tree Generation

- Existing nuclear power plant PRAs are mostly based on conventional methods i.e., *fault tree and event tree analysis*
- *Incorporation of the Dynamic Models* into existing conventional PRAs
- A *series of static fault trees* at different time steps
- Minimal cut-sets or prime implicants are all *time-stamped*

Timed-Fault Tree Construction

- Time-fault Trees are constructed by *backtracking through each of the decision tables*
- Logically and physically inconsistent branches are pruned from the tree to obtain the minimal cut-set/PIs
- Control Loop backtracking- *Redundant/occurred components pruned*
- Transition Tables *changes the time at which a particular variable occurs*

A portion of the Timed-FT



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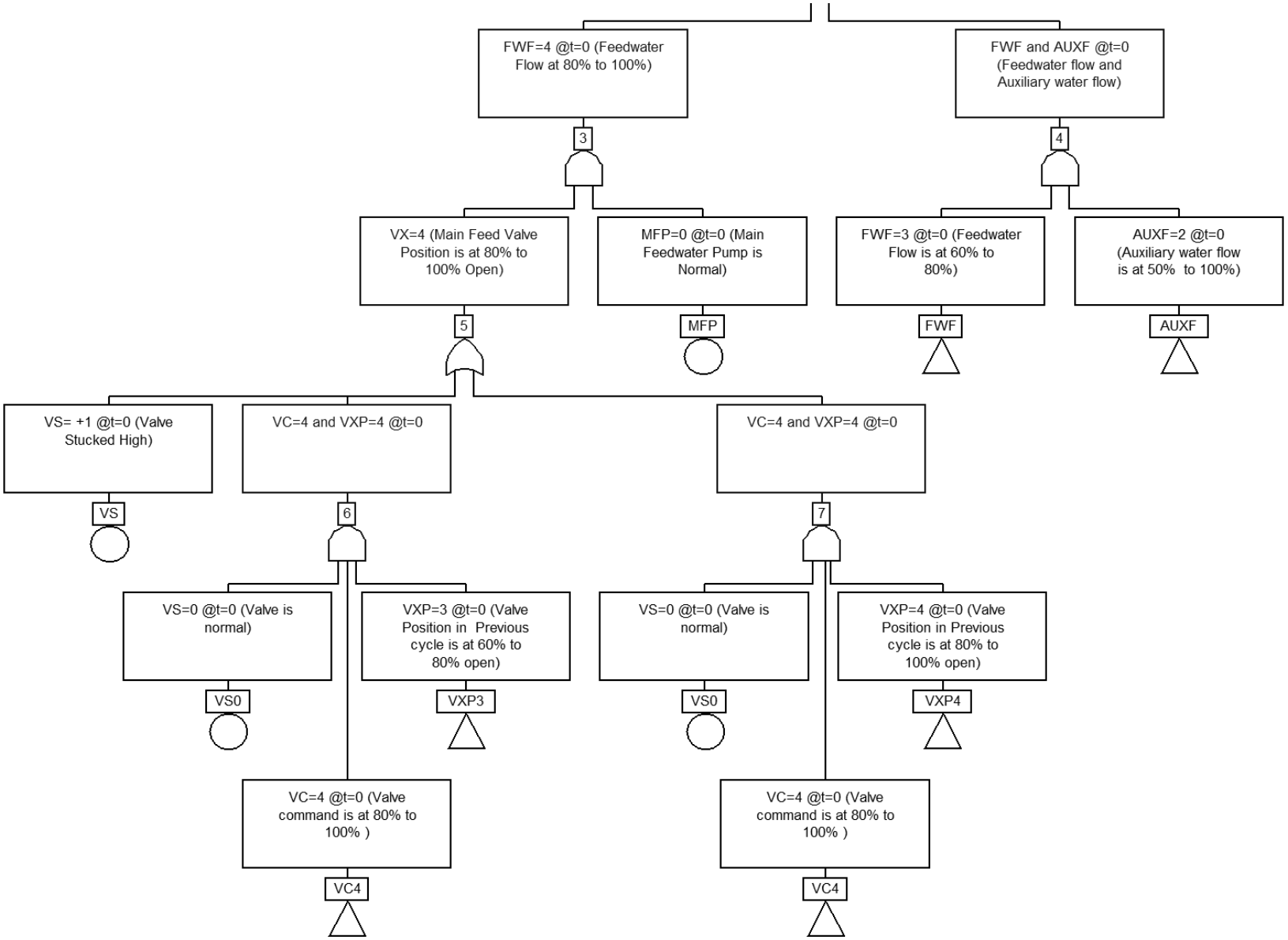

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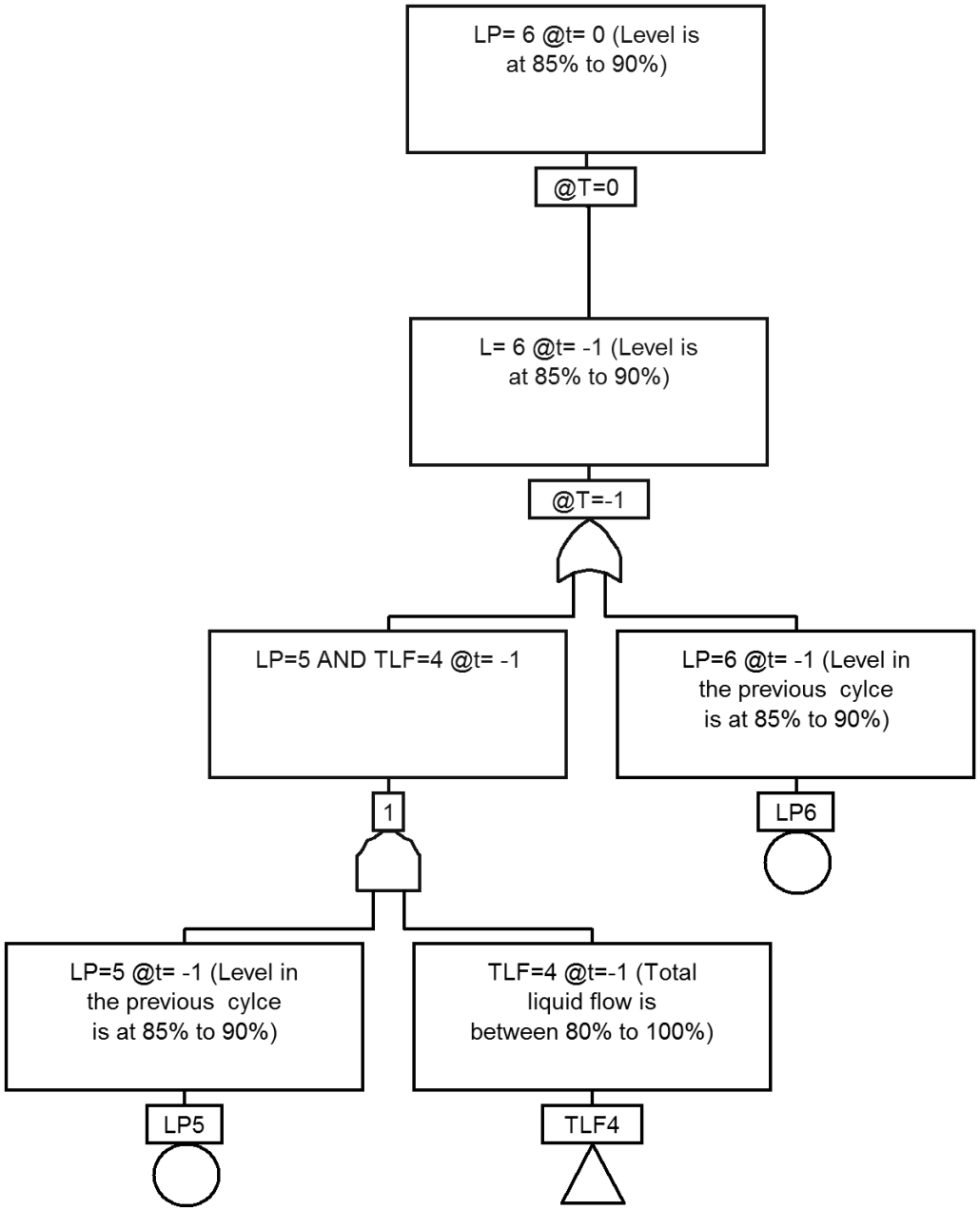

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Conclusion

- DFM provides a promising way to *adequately model and analyze digital systems* that multi-valued logic and time dependent
- Favorable approach to model dynamic systems by *explicit representation of time element* (a significant advantage over the conventional methods)
- DFM can be used as a PRA *modeling supplement for special portions of a system* that are dynamic and non-binary in behavior.

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Conclusion

- DFM Prime Implicants and minimal cut-set of the timed-fault trees agrees *(post processing)*
- *However, significant amount of time required* for post-processing of the prime implicants
- *Timed-fault trees can be incorporated* into existing PRA models to quantify the impact of a digital system

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Ongoing Research…

- System modelling utilizing *Markov/Cell-to-cell Mapping Technique*
- *Generation of Dynamic Fault Trees* from Markov/CCCMT Model
- Comparison of Fault Tree, DFM and Markov-CCMT
- *Incorporation of dynamic fault trees* into existing PRA Models *(SAPHIRE)*

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Thank You

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