Fault Tree Based Approach for System Fault Diagnostics

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Overview

- Aim of research
- System description
- Diagnostic methods
- Research outcomes
- Conclusions & Summary

Aim of Research

- Background:
  - Several researchers investigated diagnostic methods.
  - Main avenues – sequential tests and real time.
  - Some theoretical, not applied to actual systems.
- Why the need for diagnosis?
  - Improve repair process.
  - Alter missions given system state.
  - Current research lacking in area of real time and multiple faults.

Aim of Research

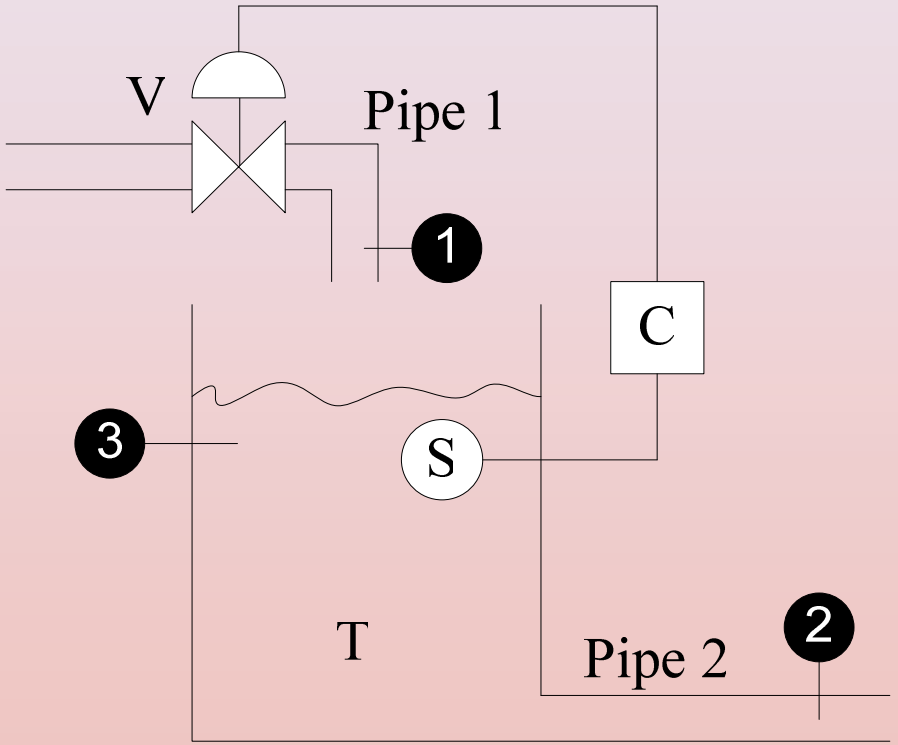
- Aim:

  Develop a diagnostic capability

  - practical
  - real time
  - multiple fault causes

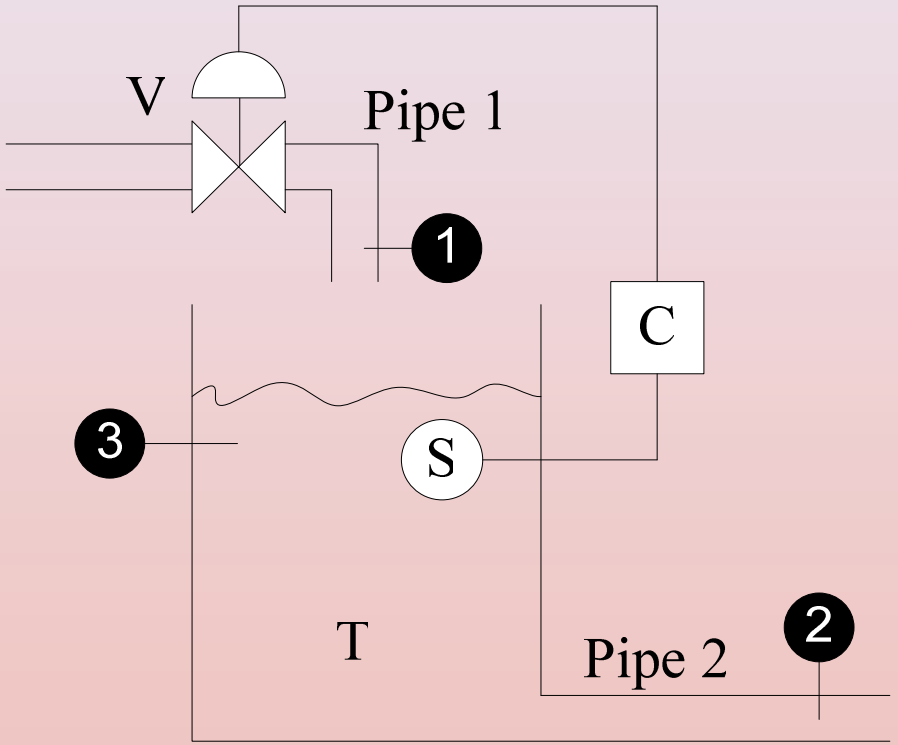
System Description

- Control system
  - V, C, & S.
- Sensors:
  - 1 Flow / No flow pipe 1
  - 2 Flow / No flow pipe 2
  - 3 Level in tank:
    High, Low, Normal

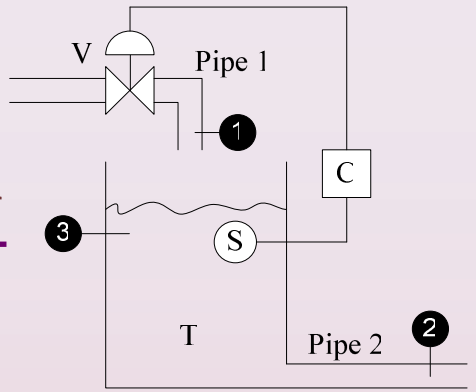


System Description

- Component failures:
  - Pipes blocked (P1B, P2B)
  - Pipes ruptured (P1R, P2R)
  - Tank Ruptured (TR)
  - Tank Leak (TL)
  - Valve fails open (VO)
  - Valve fails closed (VC)



System Description

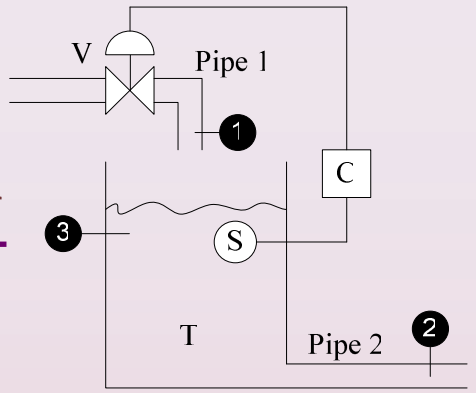


Assumptions:

Under normal operating conditions:

1. The analysis is performed under steady state conditions.
2. A rupture of the tank means that the outflow from the tank is greater than the inflow.
3. A leak within the tank means the outflow is less than the inflow.
4. Flow in through pipe 1 can be greater than the flow out through pipe 2.

System Description



Modes of Operation:

- Two modes of operation: *normal* and *inactive*.

- In *normal* operation:
  - Flow in section 1.
  - Flow in section 2.
  - Water in the tank normal.

- In *inactive* mode:
  - No flow in section 1.
  - No flow in section 2.
  - No water in the tank.

- Deviations from these expected system symptoms will indicate a fault.

Diagnostic Methods

Use of Fault Trees:

What is a fault tree?:

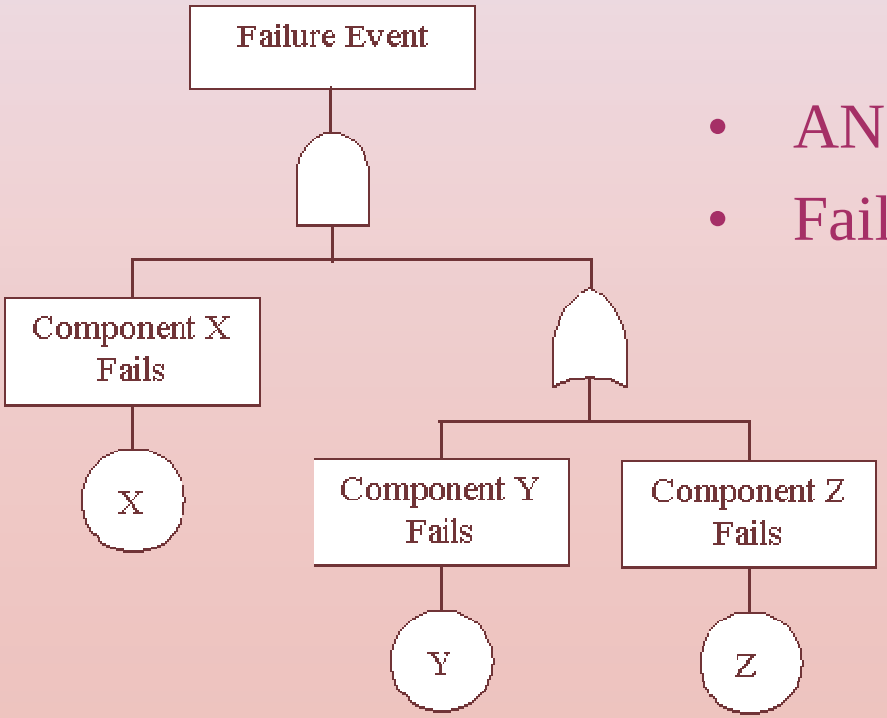
- Represents failure events.
- Successively breaks down failure event into failure causes.
- Uses deductive logic (What can cause this?).
- Provides information on the combinations of failure causes.

- Two types of fault trees – coherent and non-coherent.

Diagnostic Methods

Coherent & Non-coherent Fault Trees:

- ***Coherent***



- AND / OR logic only
- Failure events only

Diagnostic Methods

Coherent & Non-coherent Fault Trees:

- ***Non-coherent***

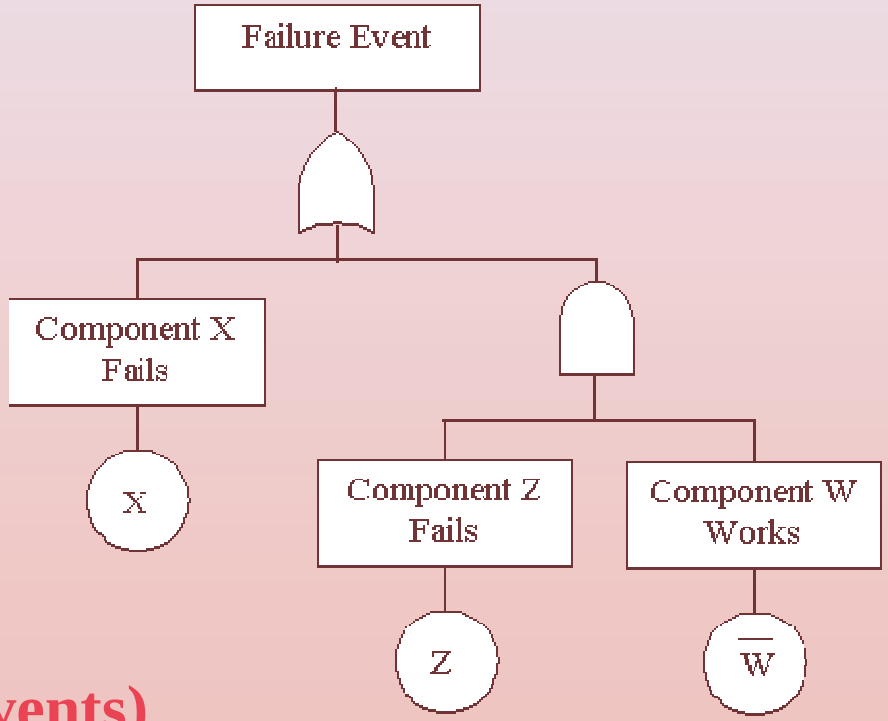
AND / OR logic

Failure events

ALSO

NOT logic

(functioning events)



Diagnostic Methods

Use of Fault Trees:

The task:

- For any unexpected system observation need to determine cause.

How achieve:

- Fault trees used to represent reasons for sensor readings – i.e. no flow in section 1.
- Sensor reading fault trees can be coherent or non-coherent.
- Cause of unexpected system observation determined by combining appropriate sensor reading fault trees.

Diagnostic Methods

Fault Trees for Sensor Readings:

- Consider the ACTIVE mode:
  - Expected readings:
    - Flow in section 1, flow in section 2, normal level in tank

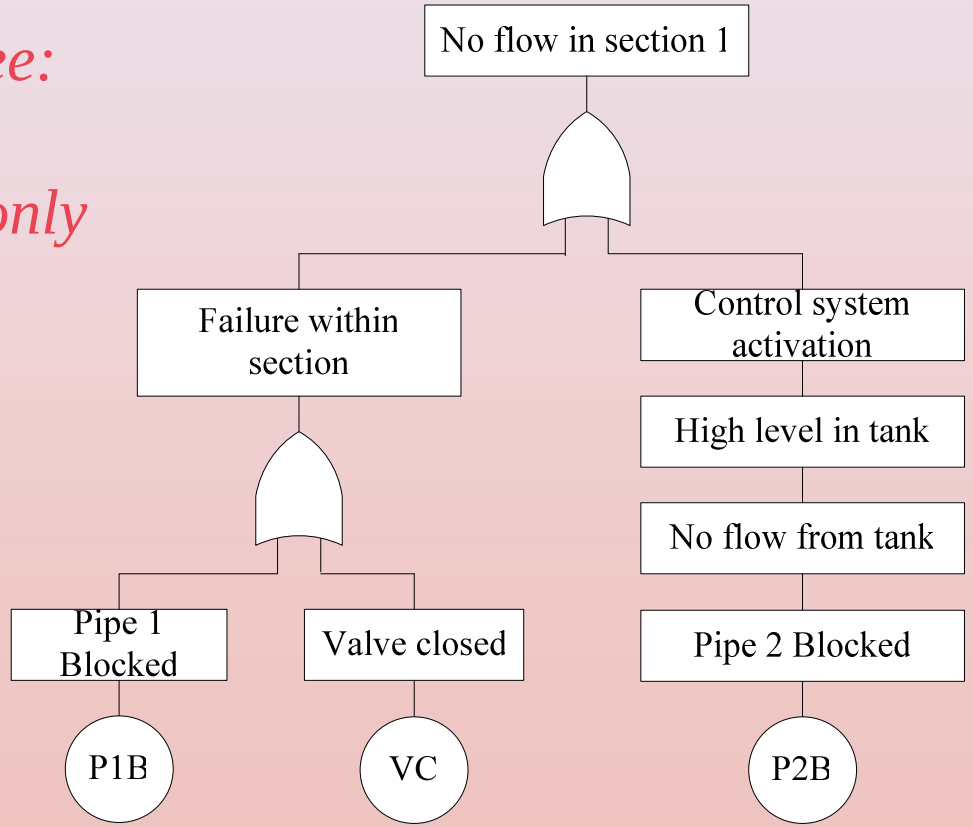
- Sensor readings of interest:
  - No flow in section 1
  - No flow in section 2
  - High water level in the tank
  - Low water level in the tank

Diagnostic Methods

Example Fault Tree for Sensor Reading:

- *Coherent Fault Tree:*
  - *AND/OR logic*
  - *Failure events only*

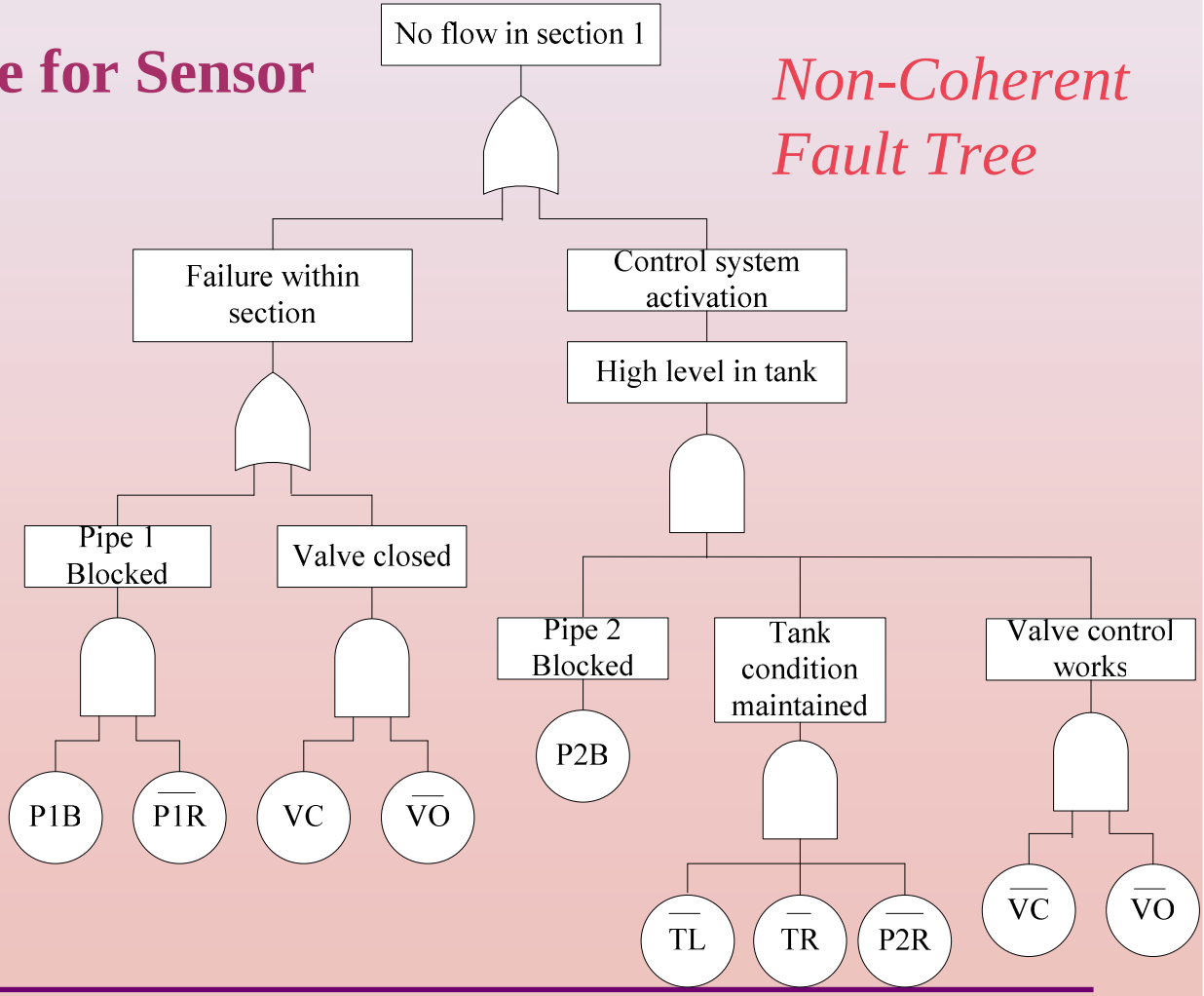
- Min Cut Sets:
  {P1B}
  {VC}
  {P2B}



Diagnostic Methods

Example Fault Tree for Sensor Readings:

Non-Coherent Fault Tree



Prime Implicant Sets:

$\{P1B.\overline{P1R}\}$

$\{VC.\overline{VO}\}$

$\{P2B.\overline{TL}.P2R.\overline{TR}.\overline{VC}.\overline{VO}\}$

Coherent Approx:
{P1B}, {VC}, {P2B}

Diagnostic Methods

Combining Fault Tree Information:

- For a given unexpected system observation the relevant sensor reading fault trees can be combined.

- Two methods of combination:
  - Diagnostic Method 1
  - Diagnostic Method 2

Diagnostic Methods

Diagnostic Method 1:

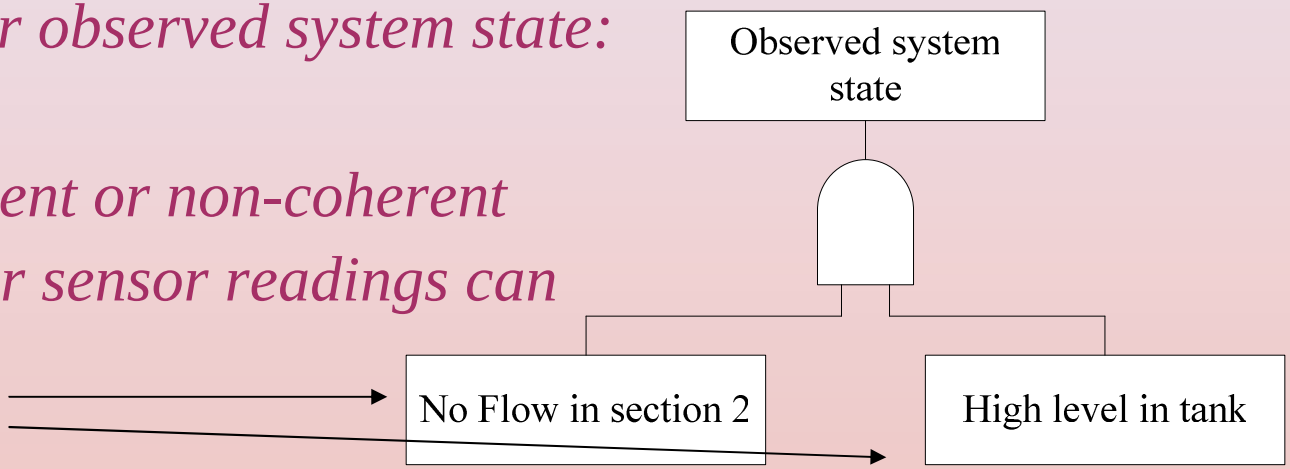
- *System Observation fault tree produced containing:*
  - *Observations which **deviate** from the expected normal operation behaviour.*
  - The sensor readings which conform to the normal operating states are ignored.

Mode	Section 1	Section 2	Tank
Normal (expected)	Flow	Flow	Normal
Observed State	Flow	***No flow***	***High***

Diagnostic Methods

Diagnostic Method 1:

- *Fault tree for observed system state:*
- *Either coherent or non-coherent fault trees for sensor readings can be used.*



Mode	Section 1	Section 2	Tank
Normal	Flow	Flow	Normal
Observed	Flow	***No flow***	***High***

Diagnostic Methods

Diagnostic Method 2:

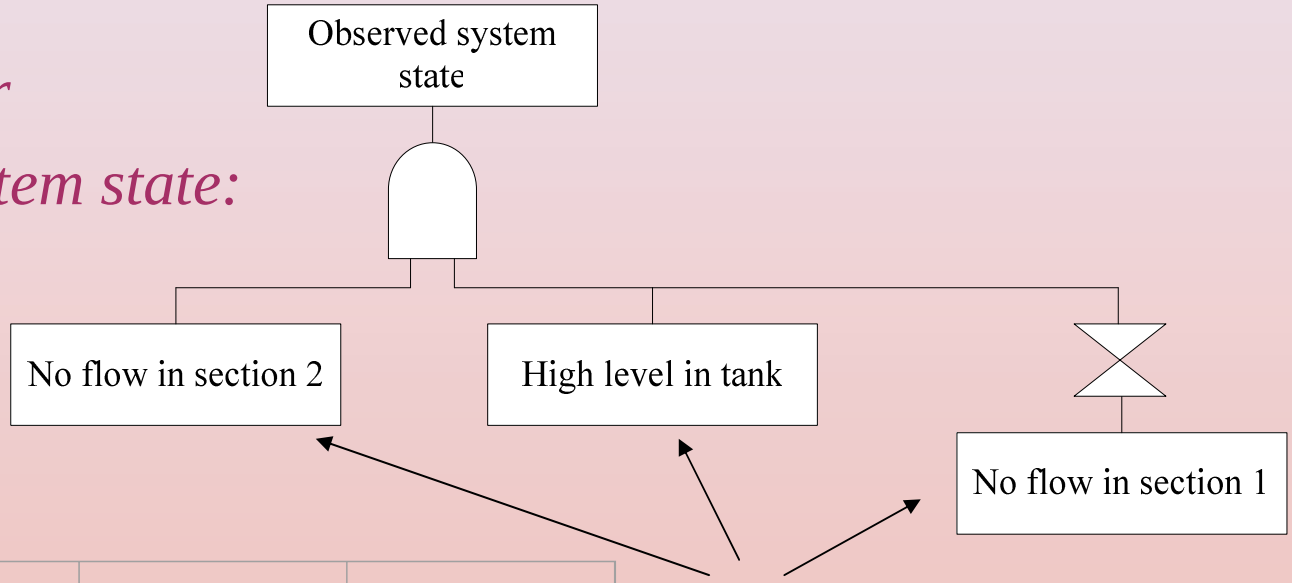
- *System Observation fault tree produced containing:*
  - *Observations which deviate from the expected normal operation behaviour.*
  - ***AND** Observations which conform to the normal operating states.*

Mode	Section 1	Section 2	Tank
Normal (expected)	Flow	Flow	Normal
Observed State	***No Flow***	***No flow***	***High***

Diagnostic Methods

Diagnostic Method 2:

- *Fault tree for observed system state:*



Mode	Section 1	Section 2	Tank
Normal	Flow	Flow	Normal
Observed	***No Flow***	***No flow***	***High***

Either coherent or non-coherent fault trees for sensor readings can be used.

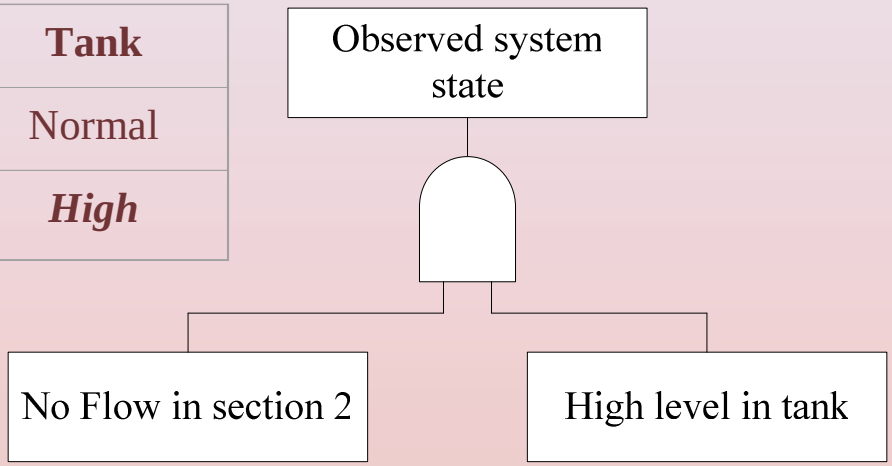
Research Procedure

- Each diagnostic method tested using coherent and non-coherent sensor fault trees.
- All possible system observations analysed.
- One example system observation demonstrated.
- Ranking procedure (importance measures) suggested for multiple cause possibilities.

Research Outcomes

Diagnostic Method 1 with coherent sensor fault trees:

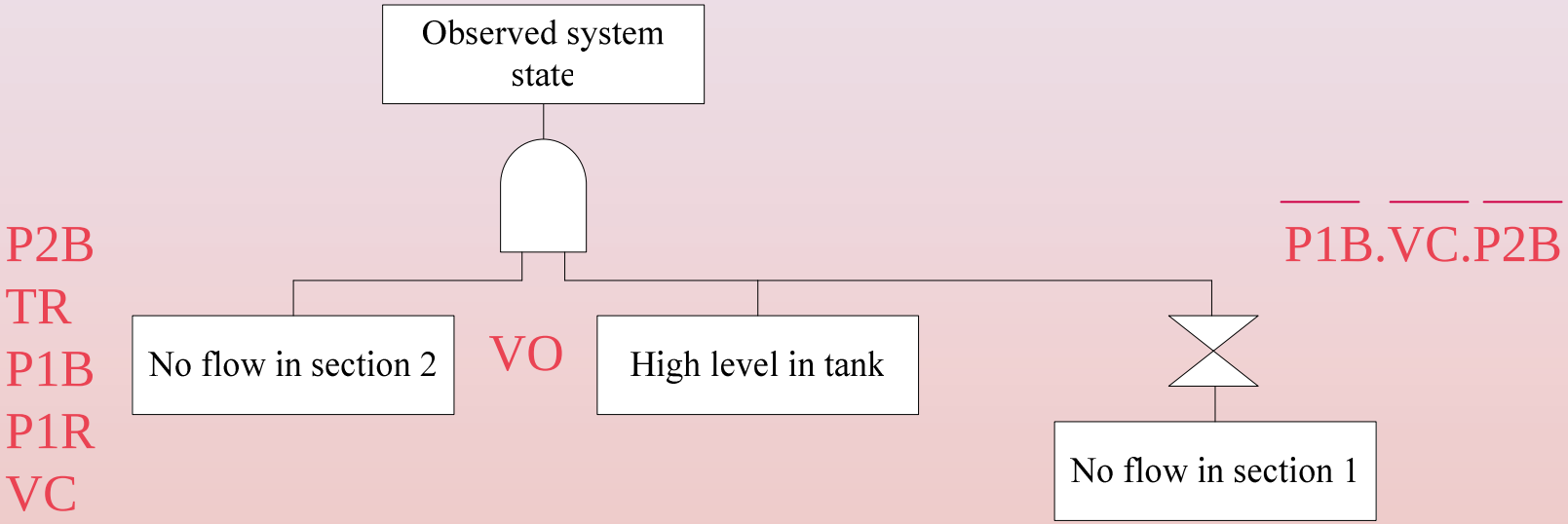
Mode	Section 1	Section 2	Tank
Normal	Flow	Flow	Normal
Observed	Flow	***No flow***	***High***



- Fault failure causes:
  - P2B.VO
  - TR.VO
  - P1B.VO
  - P1R.VO
  - VC.VO
- Invalid combinations !!

Research Outcomes

Diagnostic Method 2 with coherent sensor fault trees:



- Prime Implicants: $\{TR.VO.\overline{P1B}.\overline{VC}.\overline{P2B}\}$ $\{P1R.VO.\overline{P1B}.\overline{VC}.\overline{P2B}\}$
- Fault failure causes: $\{TR.VO\}$ and $\{P1R.VO\}$.
- Invalid combinations !!

Research Outcomes – Conclusion 1

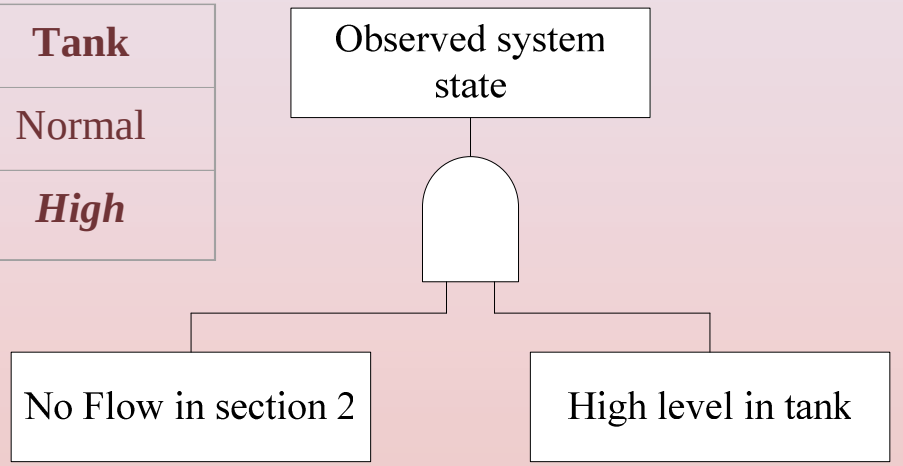
Coherent Sensor Reading Fault Tree Conclusions:

- Not sophisticated enough to determine a correct fault diagnosis.
- Incorrect fault combinations are produced with both methods 1 and 2.
- Just considering the state of the failed components is not adequate.
- Working components also need to be considered.

Research Outcomes

Diagnostic Method 1 with non-coherent sensor fault trees:

Mode	Section 1	Section 2	Tank
Normal	Flow	Flow	Normal
Observed	Flow	***No flow***	***High***



- Fault failure cause:
  - P2B.VO
- Correct diagnosis !!

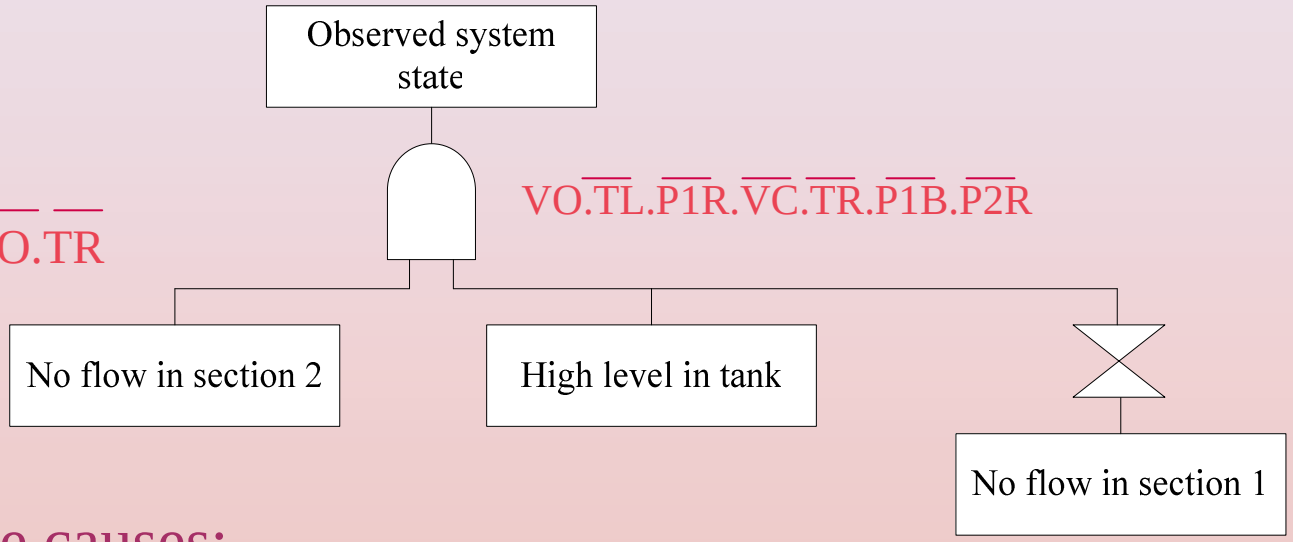
$P2B.\overline{P2R}$, $TR.\overline{TL}$,
$P1B.\overline{P2B}$, $P1B.TL.\overline{TR}$
$P1R.\overline{P2B}$, $P1R.TL.\overline{TR}$
$VC.VO.\overline{P2B}$, $VC.TL.\overline{VO}.\overline{TR}$

$\overline{VO}.\overline{TL}.\overline{P1R}.\overline{VC}.\overline{TR}.\overline{P1B}.\overline{P2R}$

Research Outcomes

Diagnostic Method 2 with non-coherent sensor fault trees:

P2B.$\overline{P2R}$, TR.$\overline{TL}$,
P1B.$\overline{P2B}$, P1B.TL.$\overline{TR}$
P1R.$\overline{P2B}$, P1R.TL.$\overline{TR}$
VC.VO.P2B, VC.TL.VO.TR



- Fault failure causes:
  - P2B.VO
- Correct diagnosis !!

{P1B.$\overline{VC}$.P2B}, {P1B.$\overline{VC}$.TL}, {*P1B*.$\overline{VC}$.P2R}, {P1B.$\overline{VC}$.TR},
{P1B.$\overline{VC}$.VO}, {P1B.VO}, {P1R.$\overline{VC}$.P2B}, {P1R.$\overline{VC}$.TL},
(P1R.$\overline{VC}$.P2R}, {P1R.$\overline{VC}$.TR}, {P1R.$\overline{VC}$.VO}, {P1R.VO}

Research Outcomes – Conclusion 2

Non-coherent Sensor Reading Fault Tree Conclusions:

- Correct failure combinations produced for the example system state observed.
- However invalid combinations produced for other system states.
- Hence, inconsistencies can be found using method 1 where the working states of the system are not considered.

Overall Conclusions

Hence, for **accuracy of diagnosis** the following is needed:

1. Non-coherent fault trees for sensor reading causes.

2. Diagnostic method 2 to construct the observed system state fault tree (i.e. the whole collection of sensor readings, including the expected observations).

Importance Measures

Ranking procedure for multiple fault causes:

- *What happens if multiple fault causes are given from the diagnosis?*
- *Need a method to show most likely cause.*
- Fussell-Vesely measure of cut set importance.
- Probabilistic measure defined as:
  - the *probability of occurrence of cut set i given that the observed system has failed*

$$\text{Imp} = \frac{\text{probability of cut set occurrence}}{\text{observed system state failure probability}}$$

Summary

- Two methods have been investigated for diagnosing possible multiple faults within a system.

- Diagnostic method 1 uses information from the deviated observations only.
  - Limitations in producing the correct list of failure combinations using both coherent and non-coherent sensor reading fault trees.
  - Fault combinations have been produced which are invalid when coherent trees have been combined.
  - Combinations produced that could not have occurred due to the status of the normally functioning parts of the system with non-coherent trees.

Summary

- Diagnostic method 2 considered also those parts of the system that are known to be functioning.
  - Inconsistent results produced using coherent sensor reading fault trees for some system observations.
  - Non-coherent fault tree representation of sensor readings proved the most successful as a diagnostic tool.
- The use of importance measures can be used to identify the most likely cause of the system fault when a number of options or possible causes are predicted.

Thank you for your attention.

Any questions????