Comparison of Digraph and Fault Tree Based Approaches for System Fault Diagnostics

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Overview

- Fault Diagnostics
  - Why important.
  - Current approaches.

- Application - Aircraft Fuel System.

- Diagnostic methods
  - Fault Tree Based
  - Digraph Based

- Results.

- Conclusions.
Importance of Fault Diagnostics

- **Why is Fault Diagnosis important?**
  - Minimise disruption to operation of system.

- **Key characteristics:**
  - Require adaptability.
  - Require identification of multiple faults.

- **Approaches to Fault Diagnosis:**
  - Testing at specific points in time.
  - Testing in real time.

- **Latest Approaches:**
  - Fault Tree based methods.
  - Use of digraphs.
Fuel System

- Represents aircraft fuel system.
- Active supply tanks: main, wing and collector.
- Engine tank treated as ‘tanker’.
- System behaviour:
  - 7 flow transmitters.
  - 6 pressure transmitters.
  - 4 level transmitters.
Two main modes of operation:
- ACTIVE & DORMANT

Two further modes:
- REFUEL & FUEL DUMPING

Component failure modes considered are:
- 43 in total.
- 30 - valves fail blocked / leaking / partially blocked.
- Tank rupture / leakage.
- Pipes rupture / leakage / blockage / partial blockage.

System assumptions.
Two methods compared:

- Fault Tree Diagnostic Method.
- Digraph Diagnostic Method.
Fault Tree Method involves:

- Step 1: Construct fault trees for observable system deviations
- Step 2: Determination of system status
- Step 3: Diagnostic fault tree construction
- Step 4: Consistency verification
- Step 5: Fault cause ranking
### Fuel System Diagnostics – Fault Tree (1)

#### Step 1 - Fault tree construction:
- 12 fault trees for sensor deviations for each tank
  - i.e. no flow/flow at flow transmitter
- Non-coherent – AND, OR and NOT logic
- Size: largest - 55 gates, 90 events
  smallest - 12 gates, 20 events

#### Step 2 – System Status
- Deviations in main tank – No Flow FT0110

<table>
<thead>
<tr>
<th>LT0110</th>
<th>FT0100</th>
<th>FT0110</th>
<th>PT0110/PT0120</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACTIVE</td>
<td>&gt;PSO</td>
<td>No flow</td>
<td>Flow</td>
</tr>
<tr>
<td>Retrieved</td>
<td>&gt;PSO</td>
<td>No flow</td>
<td>No flow</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pressure</td>
</tr>
</tbody>
</table>
Step 3 – Diagnostic Tree
– combining deviations
– causes of No flow at FT0110
Step 4 - Verification:
- Consider events true to operating mode
- Eliminates impossible failures
- Result – 83 fault combinations

Step 5 – Likelihood
- Fussel-Vesely importance ranking
- Most likely cause P117 rupture.
Diagnostic Method - Digraphs

- Qualitative causal model which illustrates the cause and effect behaviour in a system.

- Digraphs comprise:
  i. Set of nodes, representing system process variables.
  ii. Nodes are connected by edges (lines) illustrating the inter-relationships which exist between process variables.
An Example of a Simple Digraph

- M1: mass flow at location 1 - independent variable.
- M2: mass flow at location 2 - dependant variable.
- Two arcs:
  - ‘+1’ signed - normal.
  - ‘0: V1 closed’ signed - conditional.
Digraph Diagnostic Model Development

- **Digraph Model Development Involves:**
  Step 1: System Definition
  Step 2: System Unit Classification
  Step 3: Digraph Unit Model Development
  Step 4: System Digraph Formation

- **Diagnostics involves:**
  Step 5: Identifying Deviations
  Step 6: Flag Non deviations
  Step 7: Back Trace
Step 1, 2 and 3 – yields digraph
The unit model for main tank:
- 242 nodes
  - 43 process variables
  - 199 component failure modes
  - 140 of 199 being pipe failures

Full system digraph:
- 3 tanks combined.
- 842 nodes;
  - 151 are process variable nodes
  - 691 are component failure mode nodes
- Deviation at FT0110 – No flow
- PFT110(-10) → M117(-10)  
  → P117B, P117R.
- M117(-10)  
  → M108(-10) AND M116(-10).
- M108(-10)  
  → P108B/R, BP110B/C.

- 83 failure mode options:  
  ▪ 2 single order.  
  ▪ 81 second order.
Complementary perspective

Both methods require models to be constructed.

Similarities include comparison of actual and expected behaviour.

Both have produced valid and credible results.
Fault Tree Method:
- Once trees (for sensor deviations) generated analysis straightforward.
- Consistency checking required.
- Importance rankings help to hone in on actual cause.
- No investigation of faulty sensors.
- Application to dynamic behaviour not straightforward.
Method Review

- **Digraph Method:**
  - Clear representation of relationships.
  - Digraph can be quite large but sub-units aid construction.
  - Method of back tracing is very simple and can be easily automated.
  - Flagging removes inconsistencies.
  - Dynamic considerations seem possible.
  - Hone-in mechanism required.
Conclusions

- Both methods produced realistic results.
- For steady state behaviour both method usable.
- No difference for this system on diagnostic prediction.
- Most efficient method is digraphs (as internal process of consistency checking).
- More work needed on dynamics and importance of sensor location.
Thank you for your attention.

Any Questions?