Understanding control effectiveness requires structured hazards

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Background

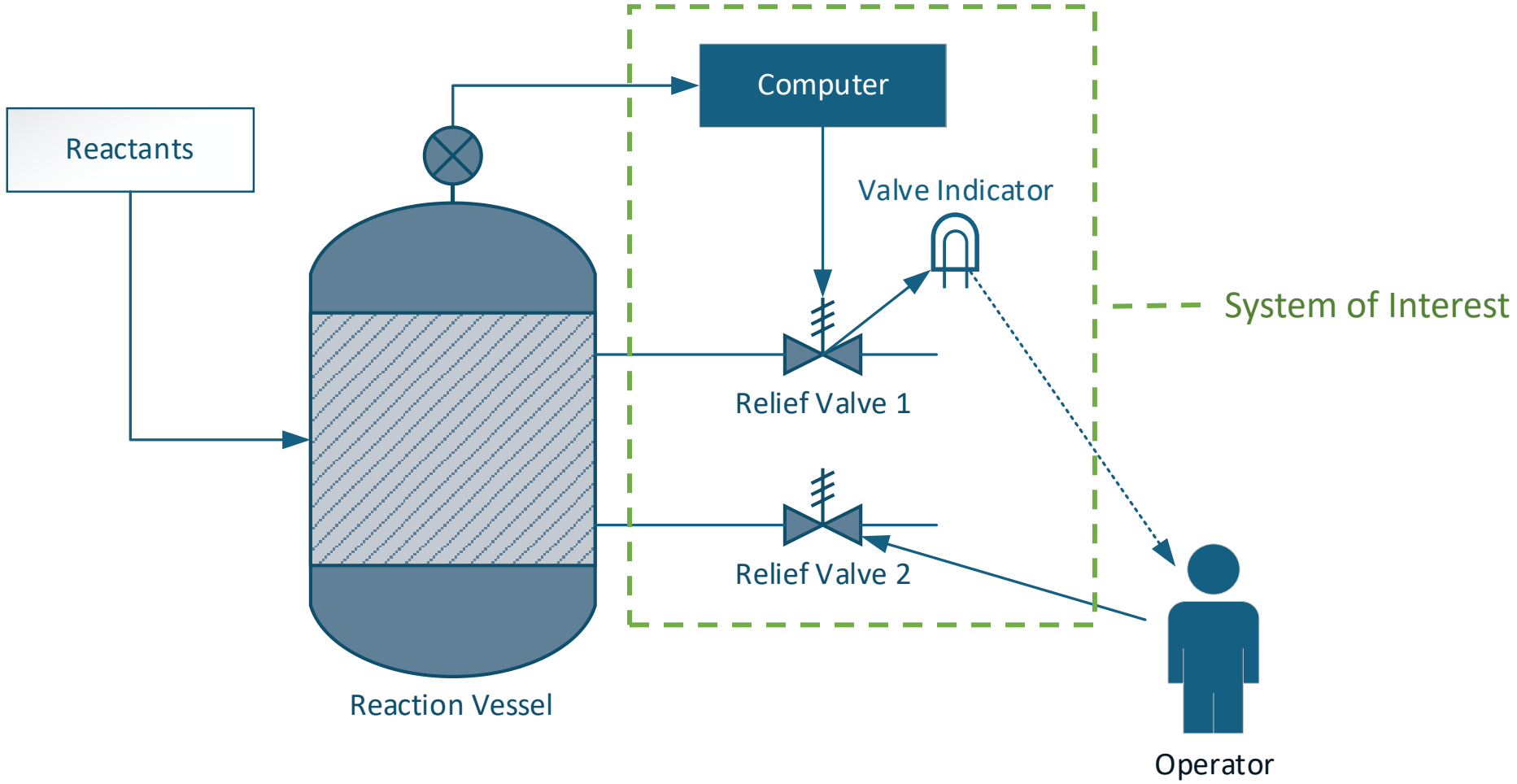
- Attempts to “rate” hazard controls in terms of (perceived) “effectiveness” are common
  - Especially in WHS contexts, but increasingly in System Safety Engineering
- Not unreasonable to ask:
  - Is this control (or set of controls) good enough?
  - [Conversely: Is it too much?]
- Alternatively:
  - Have we done everything we can or should to reduce safety risk?
  - Are we getting good “bang for buck” out of our hazard controls?

- These are not easy questions to answer…
- In attempting to do so, we need to think about:
  - How do we measure effectiveness?
  - How should we articulate hazards to enable us to do this?

Outline

- Running Example; Example Hazard Log Entry
- The Problem; What do we mean by “Control Effectiveness”?
- A Structured Approach to Hazard Logs
- Control Effectiveness – Take 2
- Using Fuzzy Logic to Assess Control Coverage
- Further Thoughts
- Conclusions

Example



Adapted from Leveson (1995): *Safeware: system safety and computers*

Example Hazard Log Entry

Hazard	Causes	Accident	Controls
Failure to manage high pressure	• Valve 1 failure • Valve 2 failure • Computer does not open valve 1 • Indicator failure • Operator inattentiveness	Explosion	• Valve reliability • Valve maintenance • Safety integrity of computer • Indicator reliability • Operator fatigue management

The Problem

Controls

- Valve reliability
- Valve maintenance
- Safety integrity of computer
- Indicator reliability
- Operator fatigue management

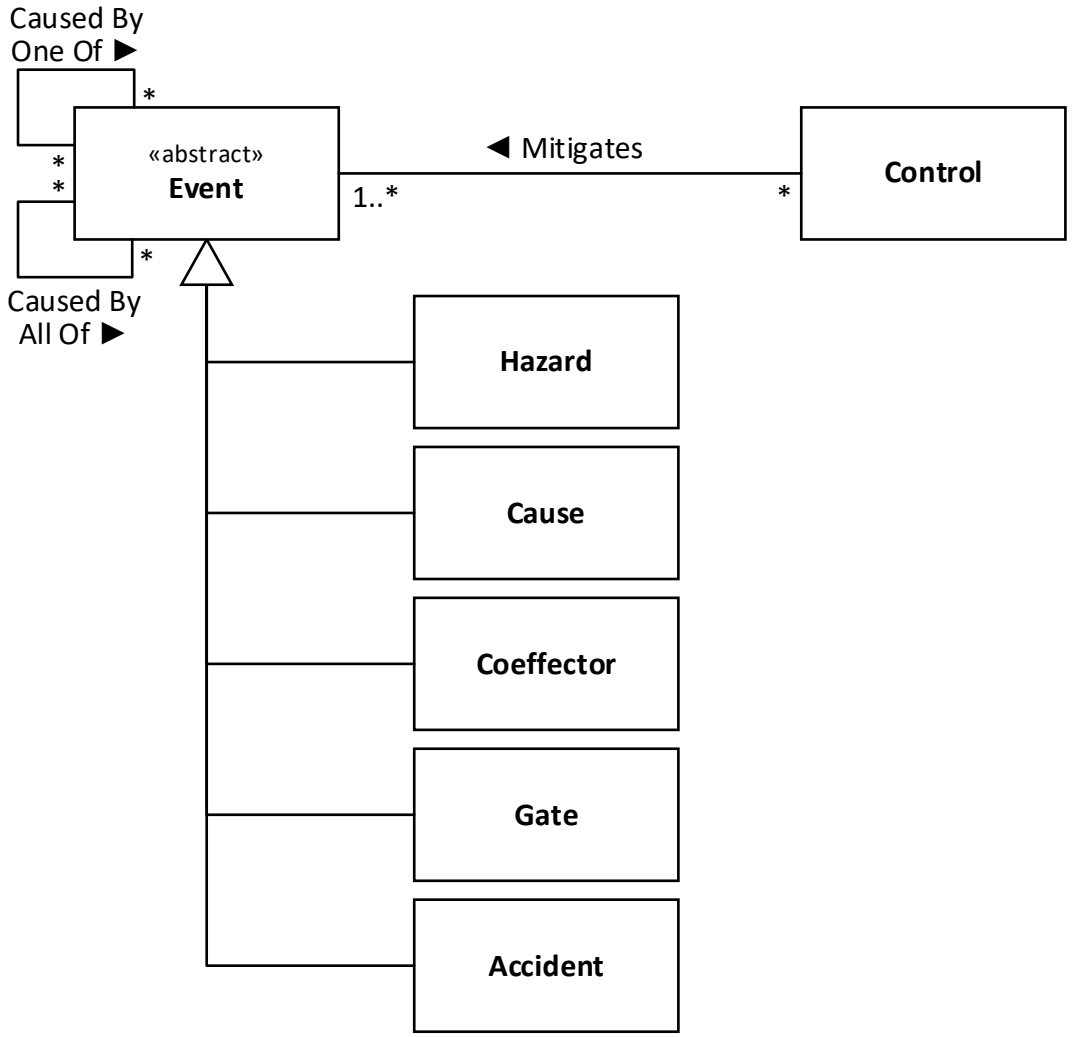
How can we estimate the effectiveness of each of these controls?

Control Effectiveness

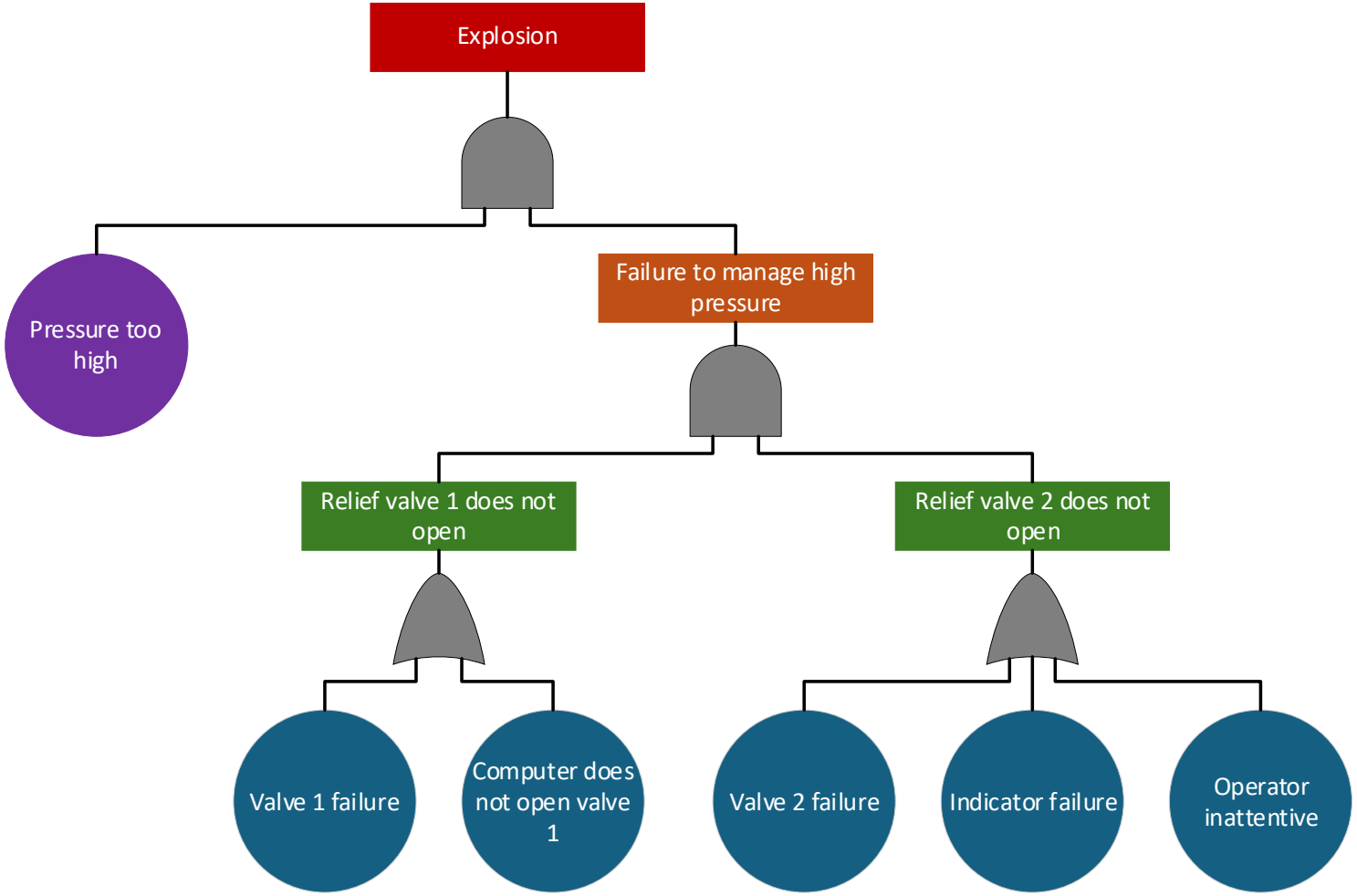
- How can we measure it?
  - A probability?
  - “T-shirt sizing”? – e.g., *Very Effective*, *Effective*, *Partially Effective*, *Ineffective*
- Effective relative to what?
  - Cause
  - Hazard
  - Accident
- Necessity vs sufficiency

A Structured Approach to Hazard Logs

- Hazard Log consists of two main types of objects:
  - Events
  - Controls
- Events
  - Include Hazards, Accidents, Causes, Coeffectors, and Gates
  - Have causal relationships
    - Caused by One Of / Caused by All Of
    - Sufficient to Cause / Necessary to Cause
- Controls
  - Associated with Events
- Although we show five event types here, this is just “convention”
  - The model supports multiple layers of hazards, where hazards at one level act as causes at a higher level
- Effectively equivalent to *fault trees*



Example Hazard as a Fault Tree



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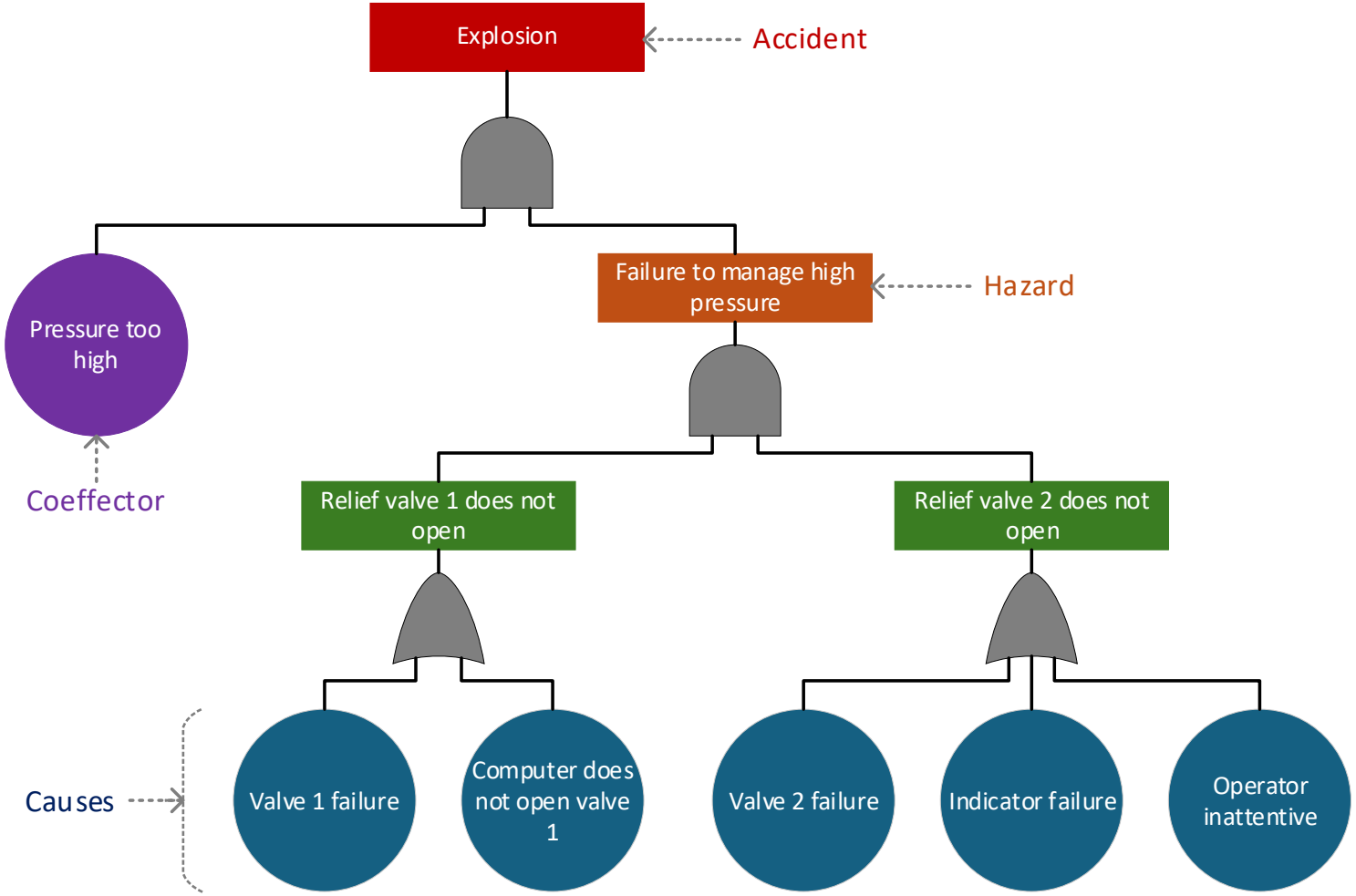

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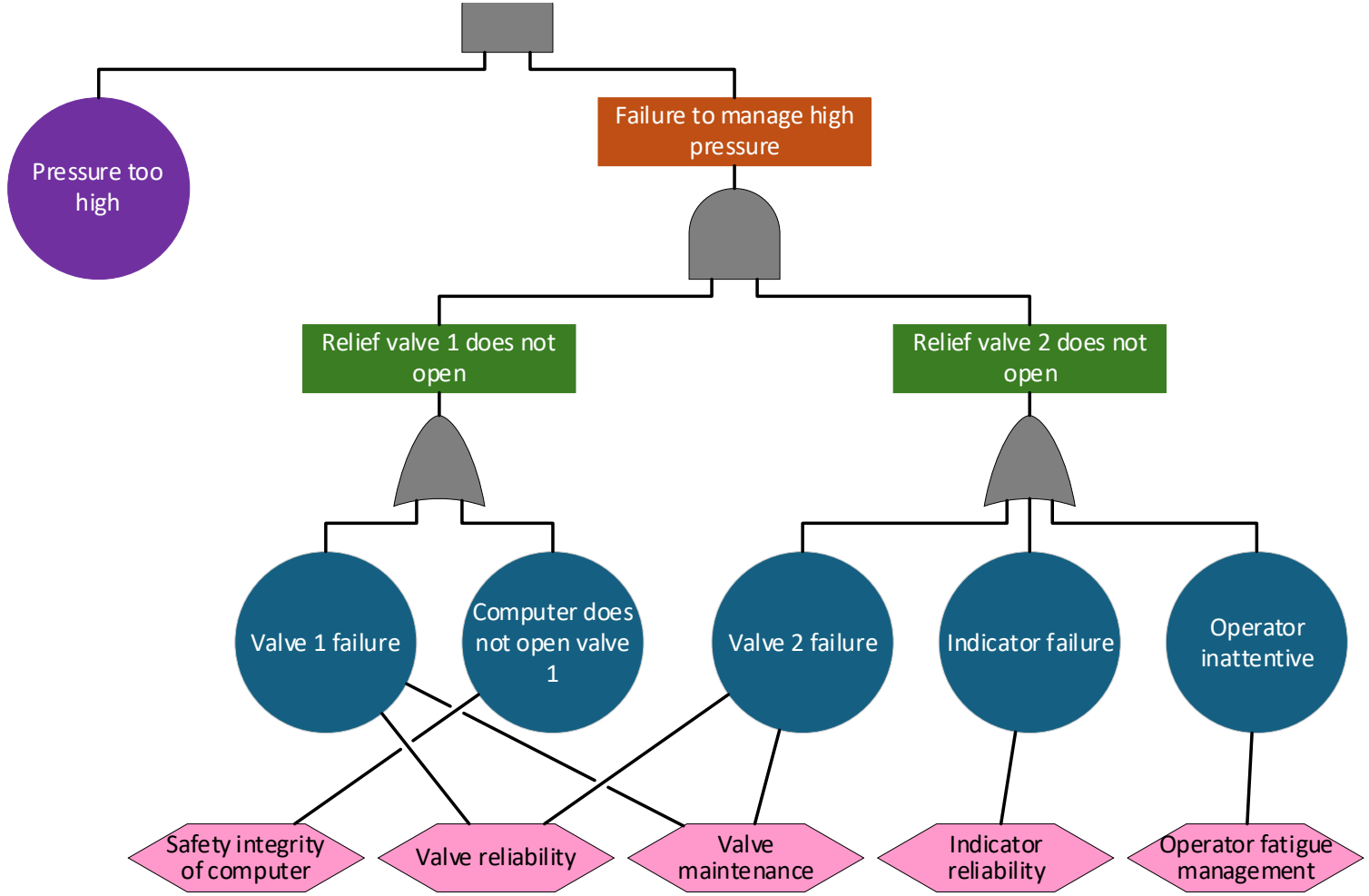
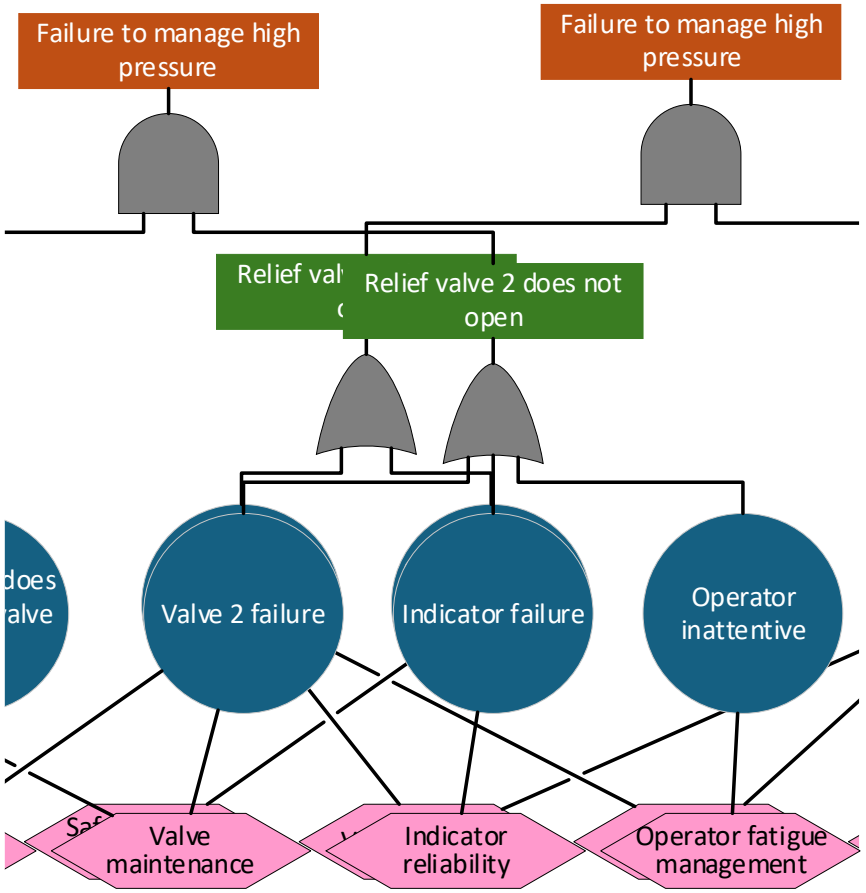


Control Effectiveness – Take 2

- How effective is “Safety integrity of computer”…
  - … against “Computer does not open valve 1”?
    - Perhaps “*Very Effective*”
  - … against “Relief valve 1 does not open”?
    - ??? – only as good as controls against “Valve 1 failure”; depends on relative likelihood of causes
  - … against “Failure to manage high pressure”?
    - ??? – as above

- How effective is “Operator fatigue management”…
  - … against “Operator inattentive”?
    - Maybe only “*Partially Effective*”
  - … against “Relief valve 2 does not open”?
    - ??? – only as good as controls against “Valve 2 failure”, “Indicator failure”; depends on relative likelihood of causes
  - … against “Failure to manage high pressure”?
    - ??? – as above



Control Effectiveness – Take 2

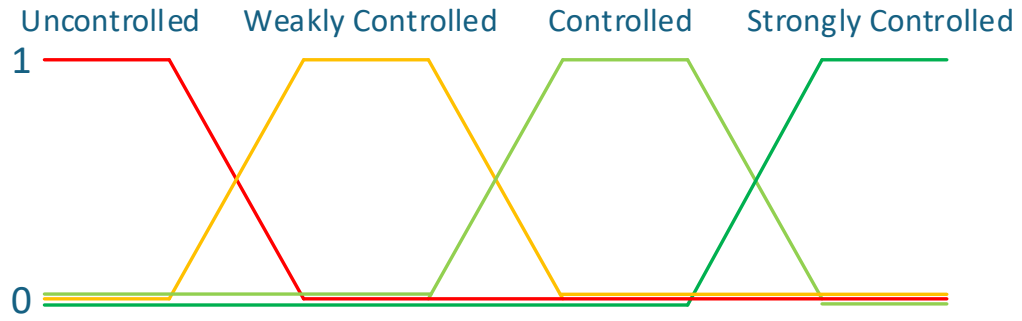
- It seems that we cannot really answer the question “how effective is this control?”
  - … except in the simplest of cases

- Instead we should ask…

How effectively controlled is this event?

Using Fuzzy Logic to Assess Control Coverage

- Fuzzy Logic enables “computing with words”, making deductions with inexact knowledge
- A Fuzzy Set is a class of objects with a continuum of grades of membership
  - E.g.: We could define a Fuzzy Set to represent control coverage:
    - *Strongly Controlled*, *Controlled*, *Weakly Controlled*, *Uncontrolled*
    - Work in terms of “degree of membership”

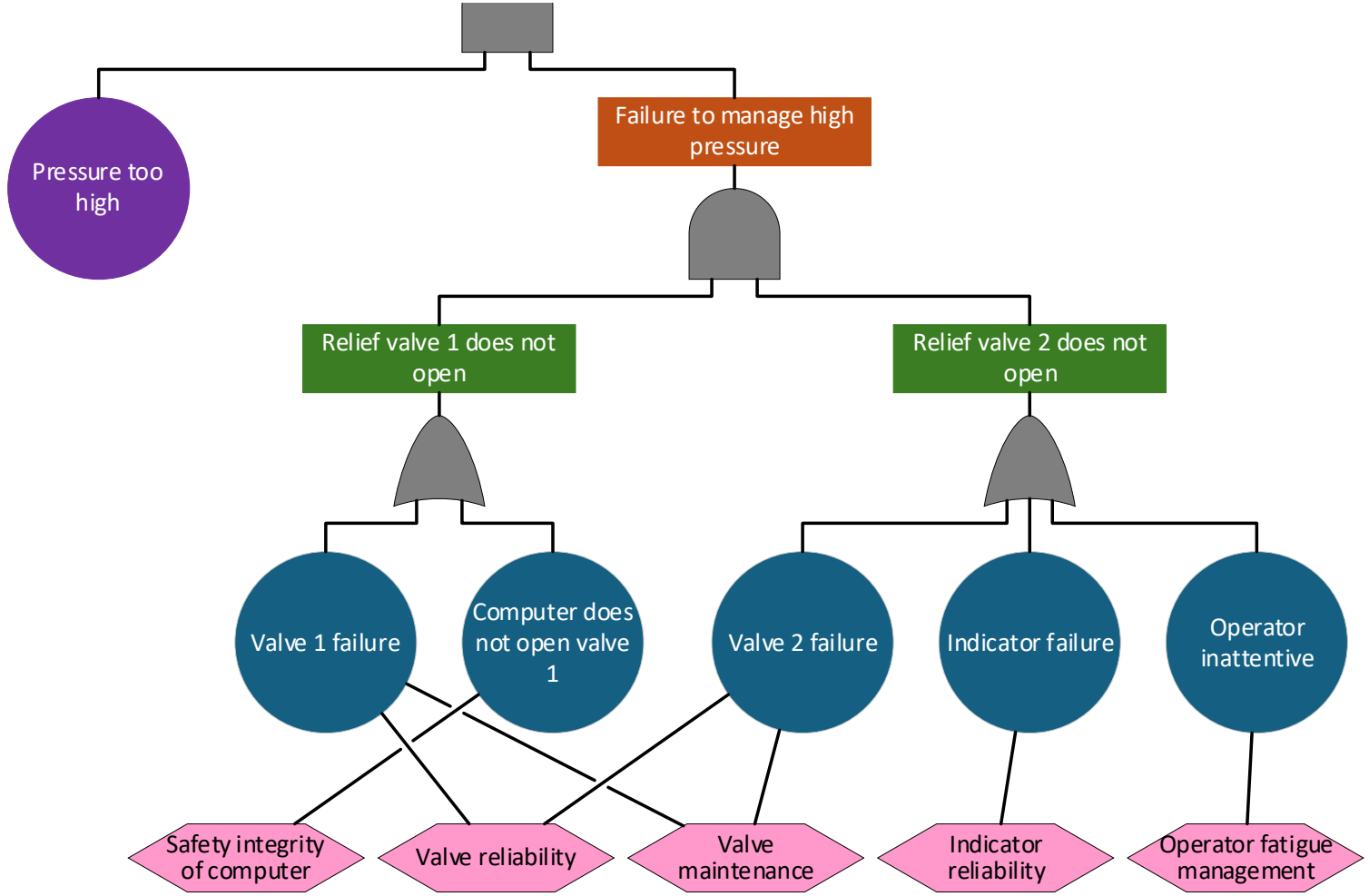


Using Fuzzy Logic to Assess Control Coverage

1. Evaluate how effectively each basic event is controlled
   - Use “T-shirt sizes” like *Strongly Controlled, Controlled, Weakly Controlled, Uncontrolled*
2. Propagate estimates “up” the tree, using fuzzy logic to evaluate each node
   - AND gate: Take the maximum measure from antecedent events
   - OR gate: Take the minimum measure from antecedent events

   - These are referred to as the “Zadeh operators”
     - (Actually… what is described here is dual to the Zadeh operators)

Using Fuzzy Logic to Assess Control Coverage



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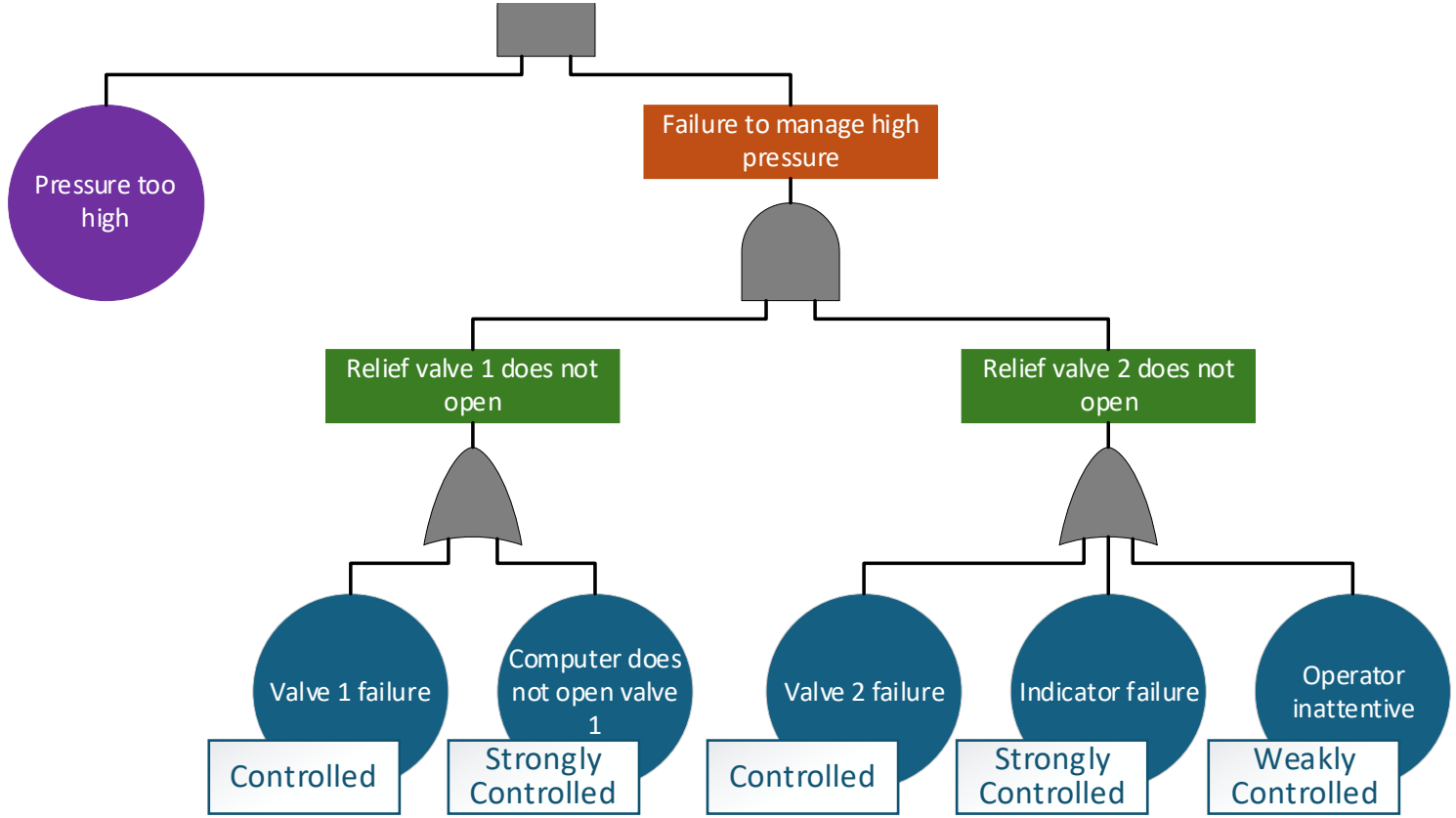

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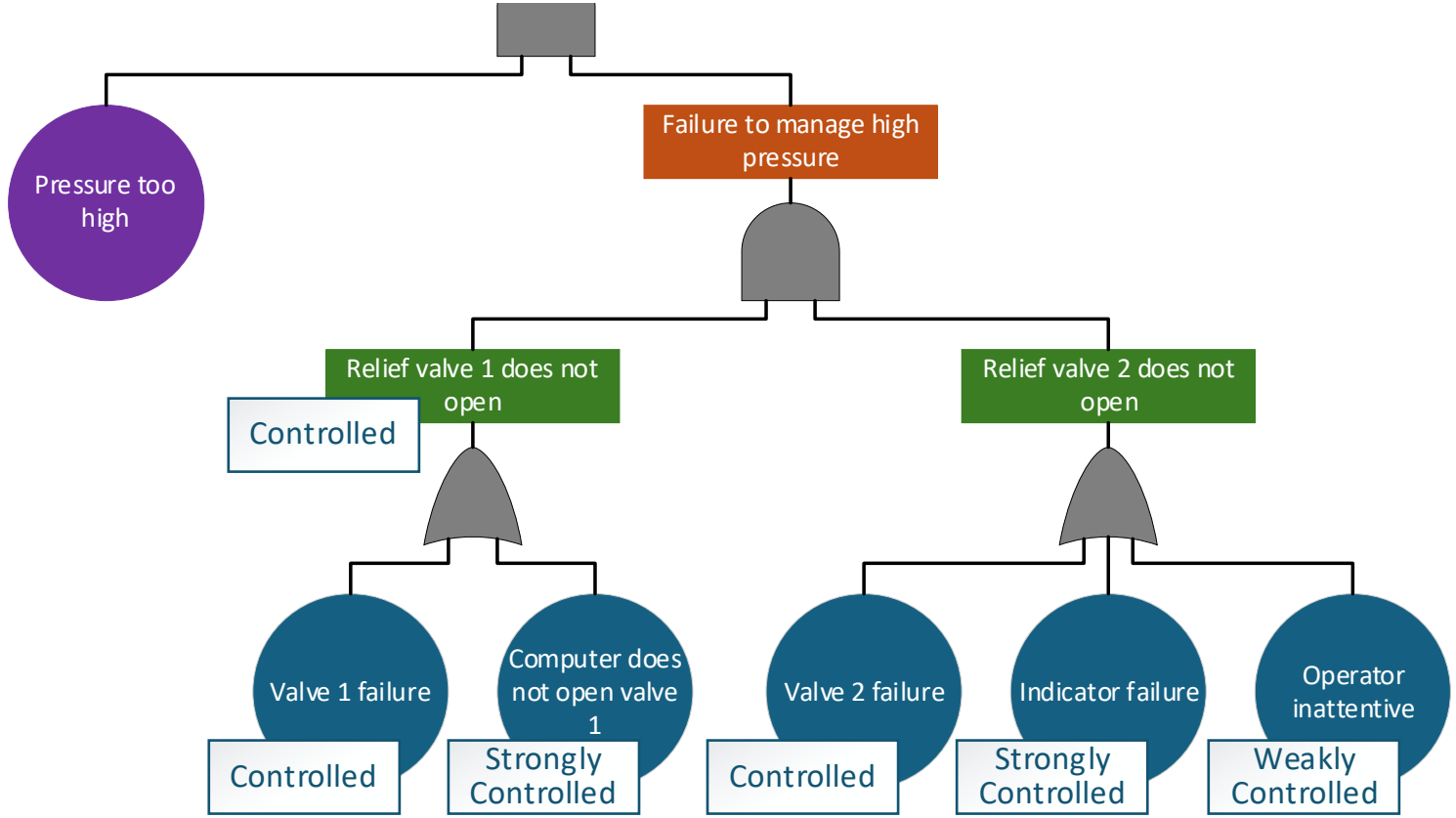

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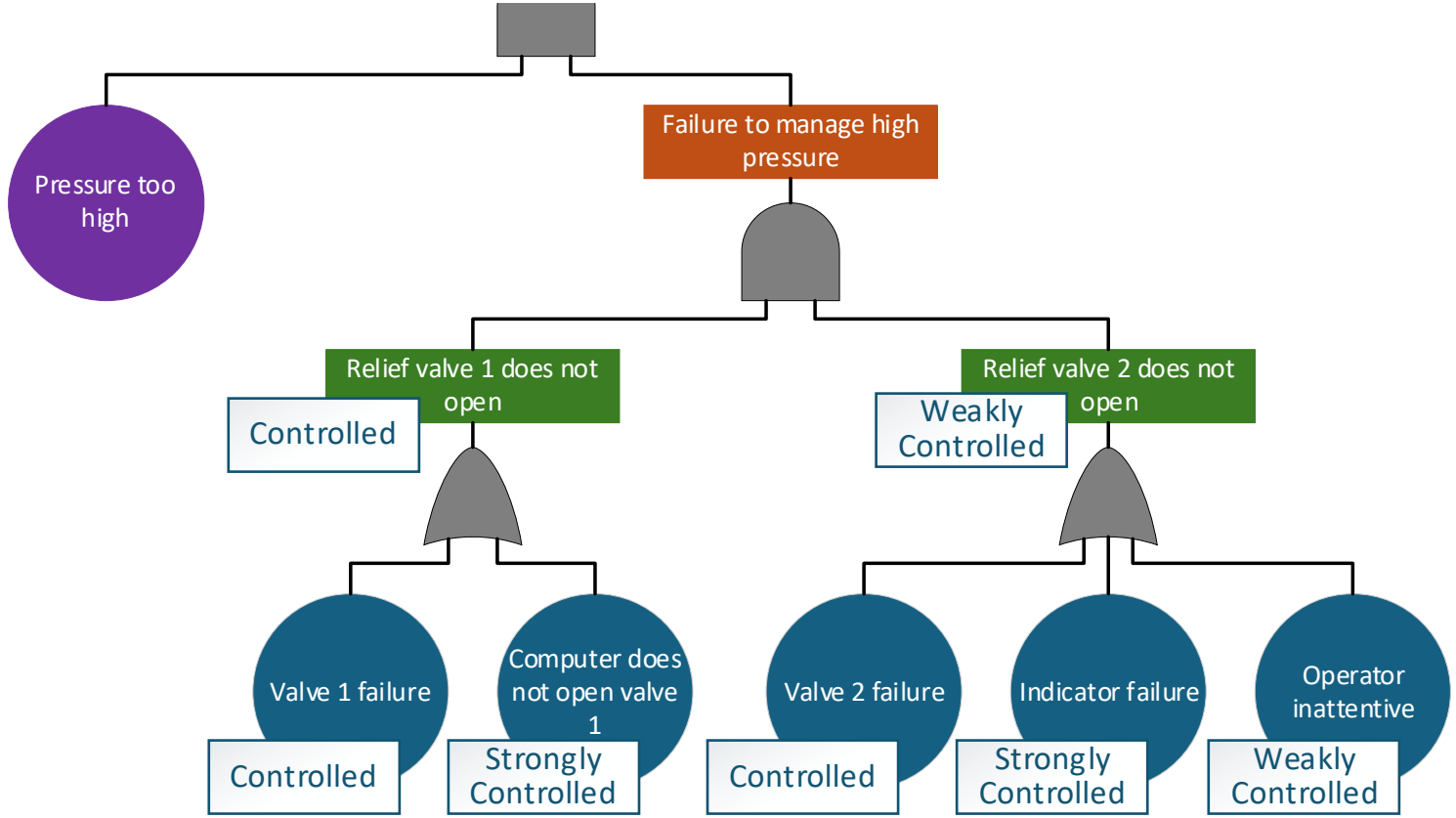

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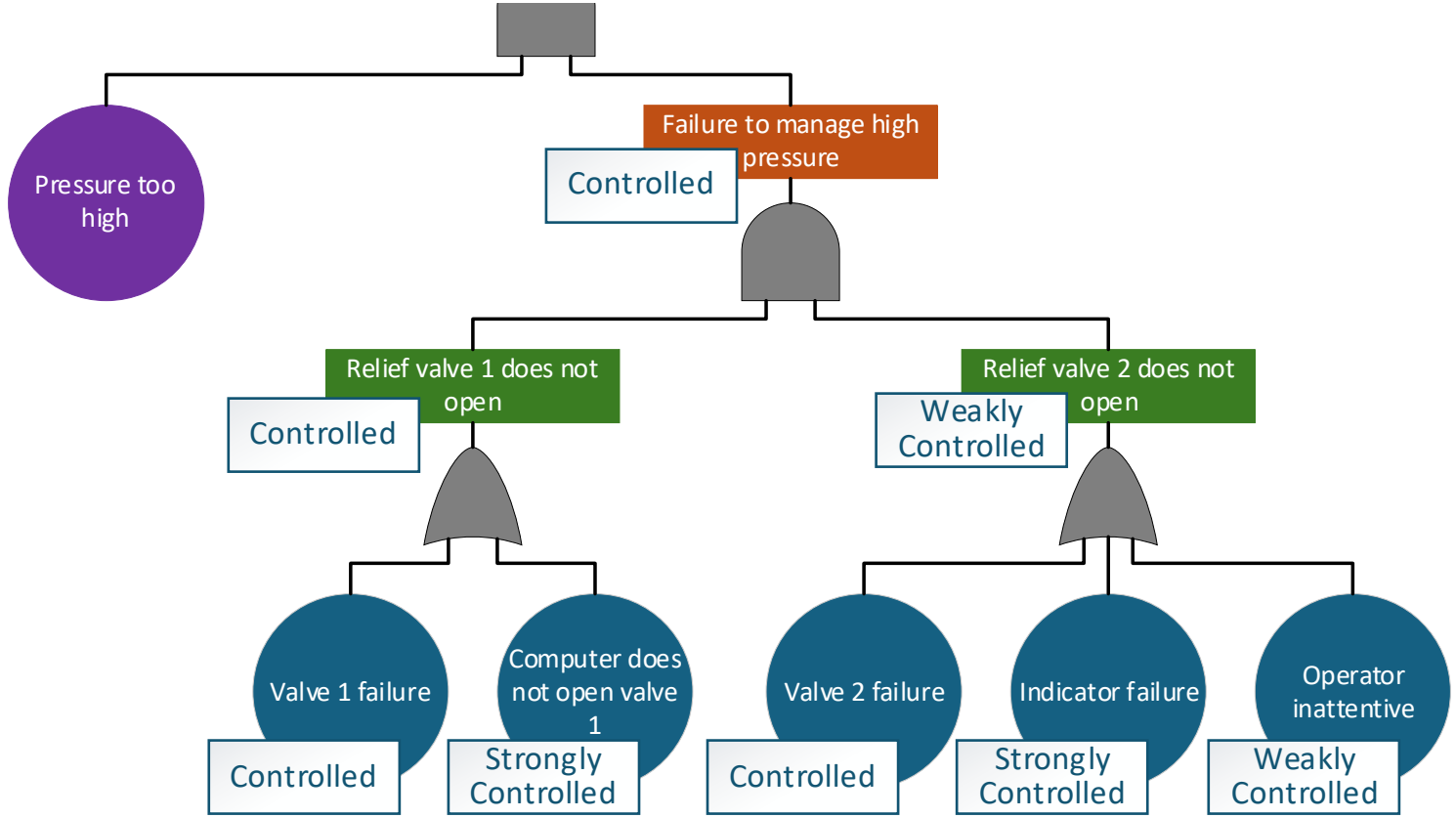

Using Fuzzy Logic to Assess Control Coverage

- Note: The measure applied to the hazard is not a measure of risk
  - But can inform the assessment of Residual Risk

- Can we do better?
  - There are alternatives to the Zadeh operators
  - However, these would require more information:
    - Relative likelihood of antecedents of OR gates
    - Propensity for common cause events among antecedents of AND gates
  - We would also need to much more carefully calibrate our Fuzzy Set

  - This would still be a lot easier than full quantification of fault trees

Further Thoughts

- This is a relatively simple method that can be applied to a Hazard Log
- … But it requires the Hazard Log to be suitably structured
  - The generic Hazard Log structure presented here has worked well on a variety of projects
- The structured approach to Hazard Logs has many other benefits
  - Well-suited to “systems-of-systems”
  - Amenable to quantification of risk
- We believe that storing such structure *in* the Hazard Log itself is important
  - Different “views” of Hazard Log information can be developed if needed
  - E.g., We have developed software to transform this structure into bow-tie diagrams
- When in the project lifecycle should this structure be developed?
  - We view this as part of the transition from *Preliminary Hazard Analysis* to *System Hazard Analysis*
  - It is hard to apply this sort of structure “after the fact”
- The process of reasoning about control coverage is perhaps as valuable as the outcome

Conclusions

- Reasoning about control effectiveness is not as simple as labelling controls “Effective”, “Partially Effective”, etc.
- Better to ask “How well controlled is this hazard (or event)?”
- Symbolic/semi-quantitative approaches to systematically answering this question are possible
  - One such method, based on Fuzzy Logic, was presented
  - It requires hazards be suitably structured
- Simple and general approach to structured Hazard Logs
  - We have used this approach successfully on a number of projects
  - We plan to continue developing (software-supported) methods of viewing and reasoning about the contents of such Hazard Logs