AI-based Automated HAZOP (MetA-HAZOP)

Marius Bächle (CSE Institut) – 5th European Congress on Plant & Process Safety

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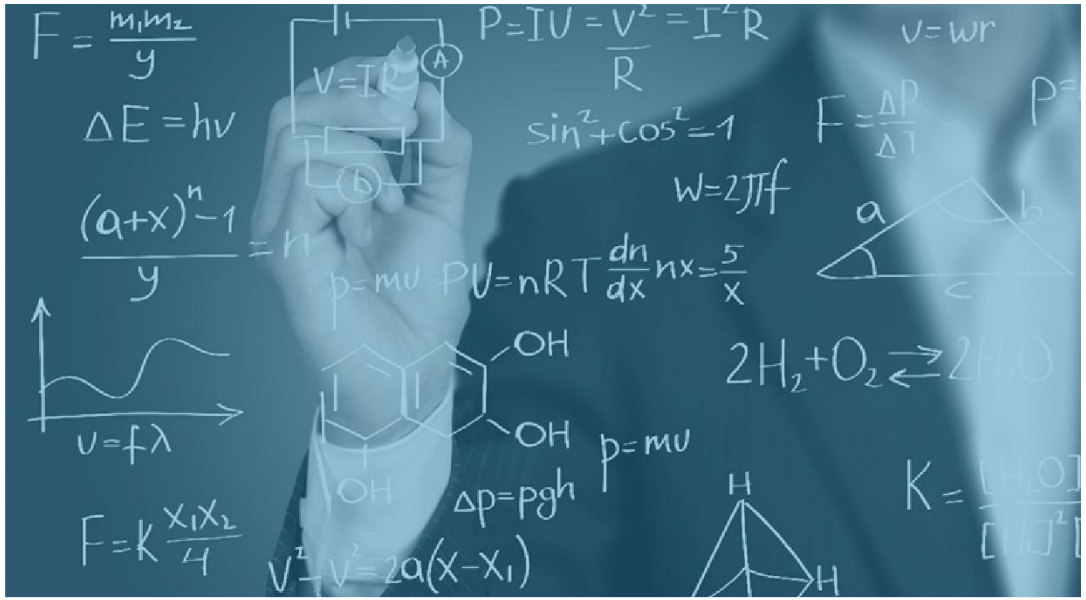
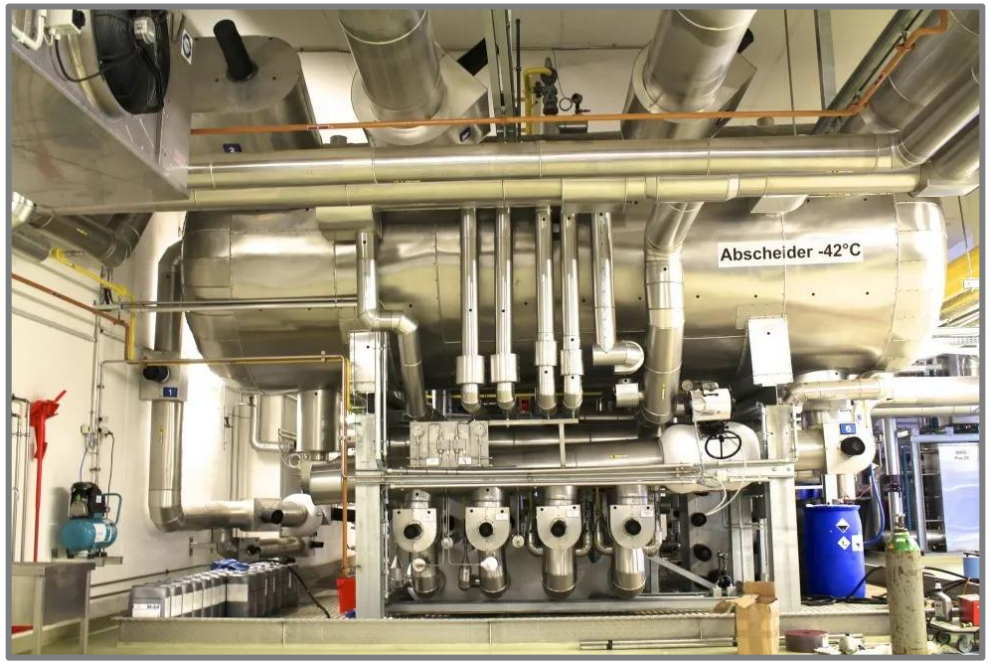
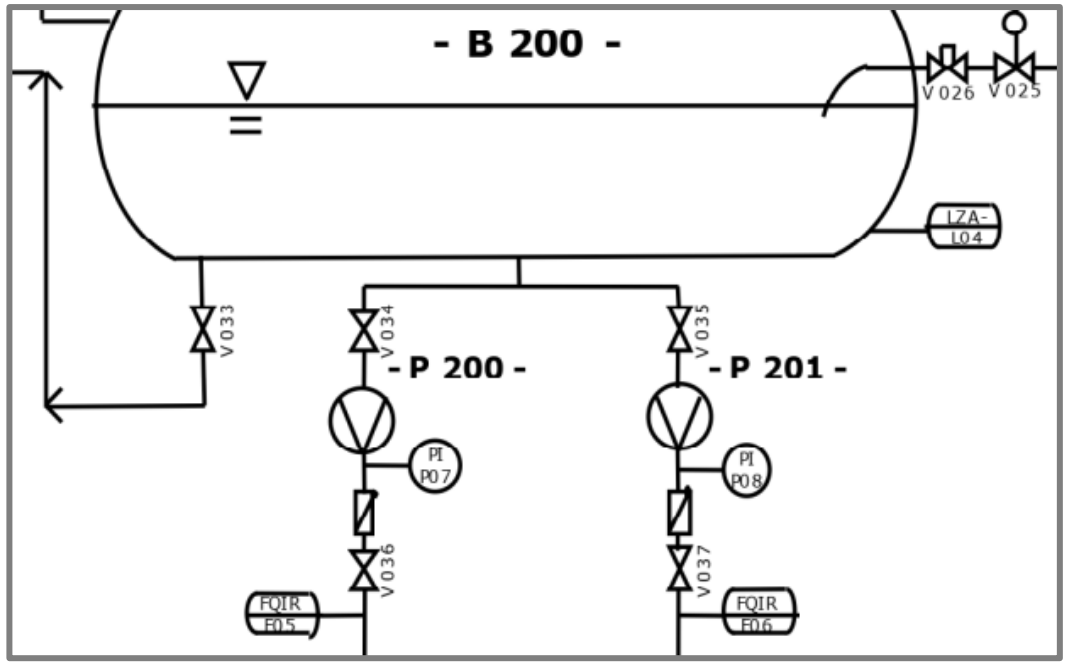


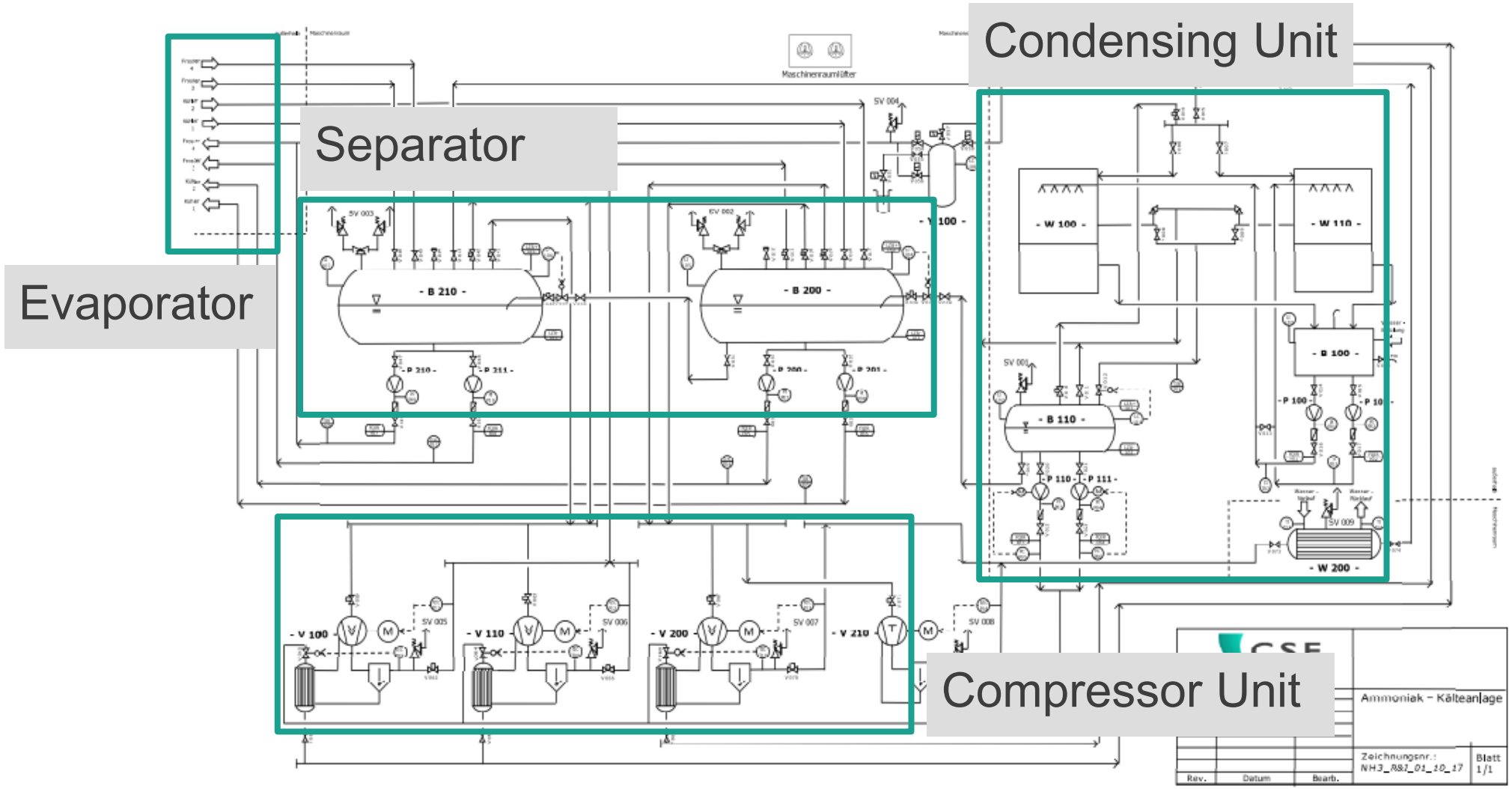
Ammonia Refrigeration Plant

- Storage of fresh and processed food
- Normal and Low Temperature Cooling stage
- Refrigerant Charge of 15 t Ammonia





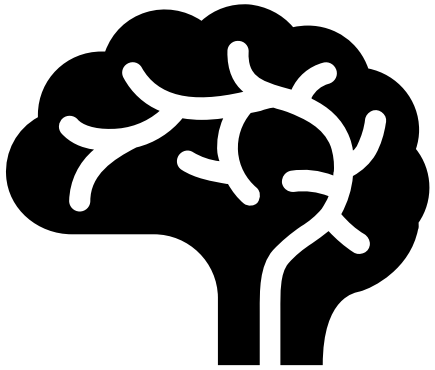
Ammonia Refrigeration Plant



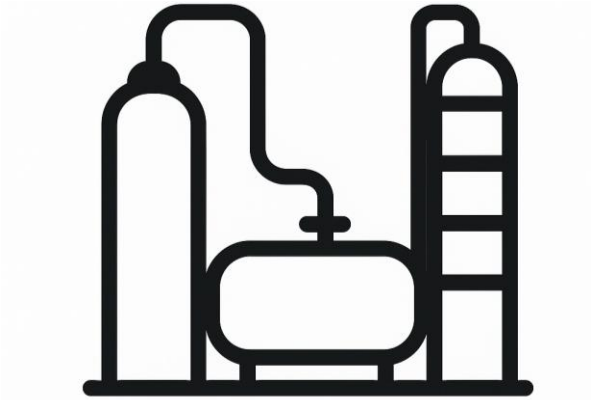
HAZOP for the Ammonia Refrigeration Plant

- 20 hours in multiple HAZOP sessions
- 5–6 experts required
- High personnel costs
- Delays due to absence of team members
- Results depend on team experience

Automated HAZOP for the Refrigeration Plant



- Safety-related know-ledge of the plant



- Digital representation of the plant

- Algorithms to identify hazardous scenarios

Required Knowledge for automated HAZOPs

Scenario Elements

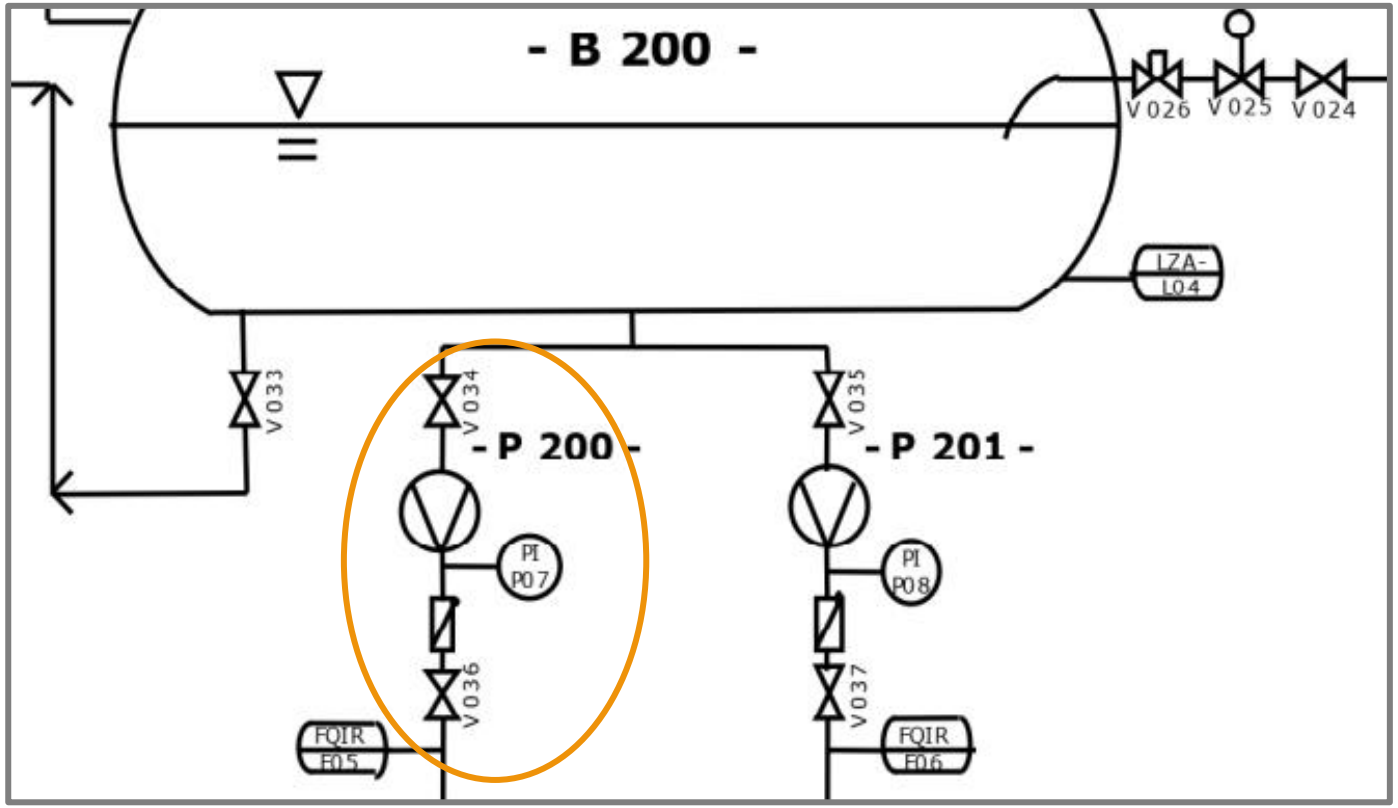
Deviation	Cause	Consequences	L	S	R	Countermeasures
No Flow	Valve V034 / V036 unintentionally closed (human error)	Overheating of Pump P200, Failure Sealing, Release of Ammonia	F0	S1	B	Valve secured in open position

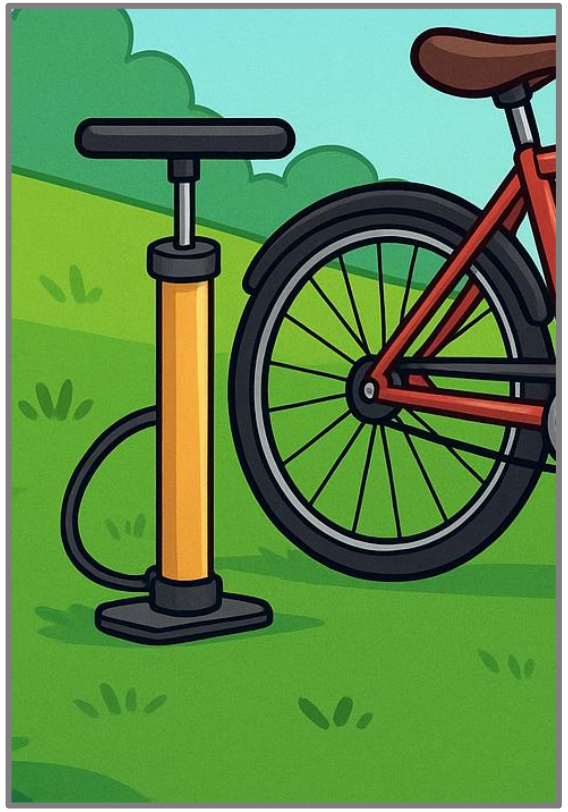
Plant and Component Data **Substance** **Risk Assessment**

- Knowledge Representation with Ontologies

Knowledge Representation with Ontologies

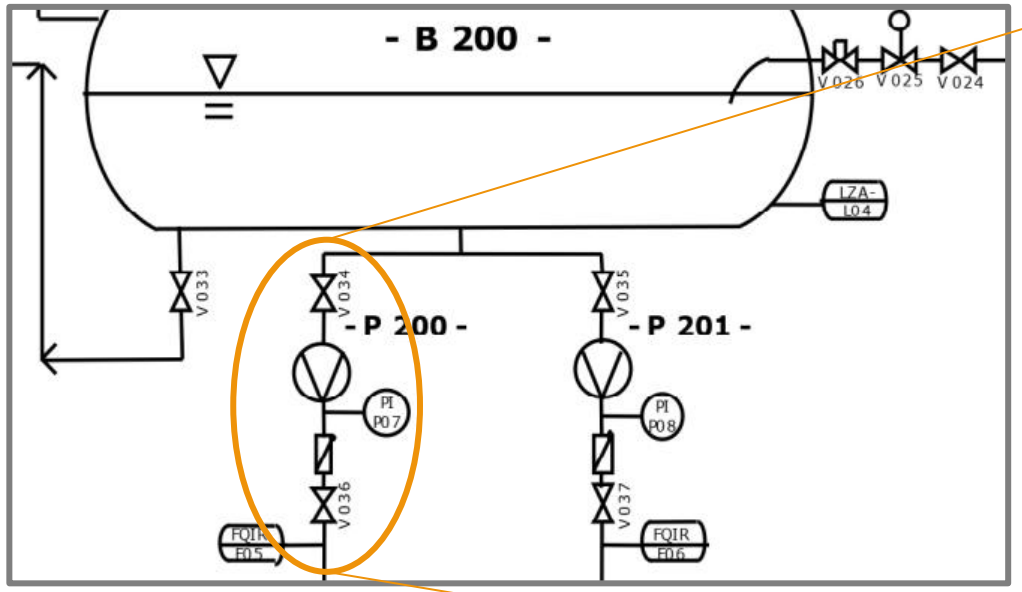
- Ontologies: Describing the Pump P200 from a Safety Perspective





Knowledge Representation with Ontologies

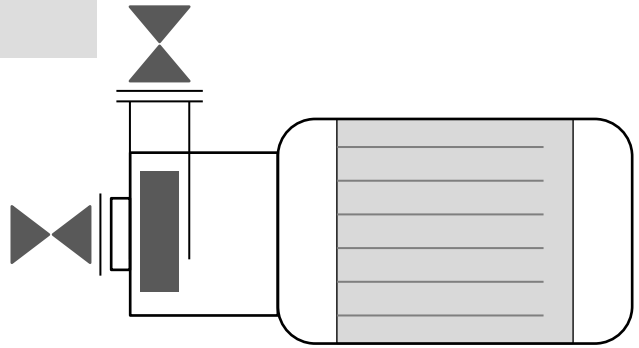
- Ontologies: Describing the Plant from a Safety Perspective
- Modelling Equipment with Classes and Relations



Refrigeration Pump P200

Pump Unit

- Centrifugal Pump
- max. Pump Pressure = 3 bar
- Non Return Valve
- Block Valve
- Block Valve



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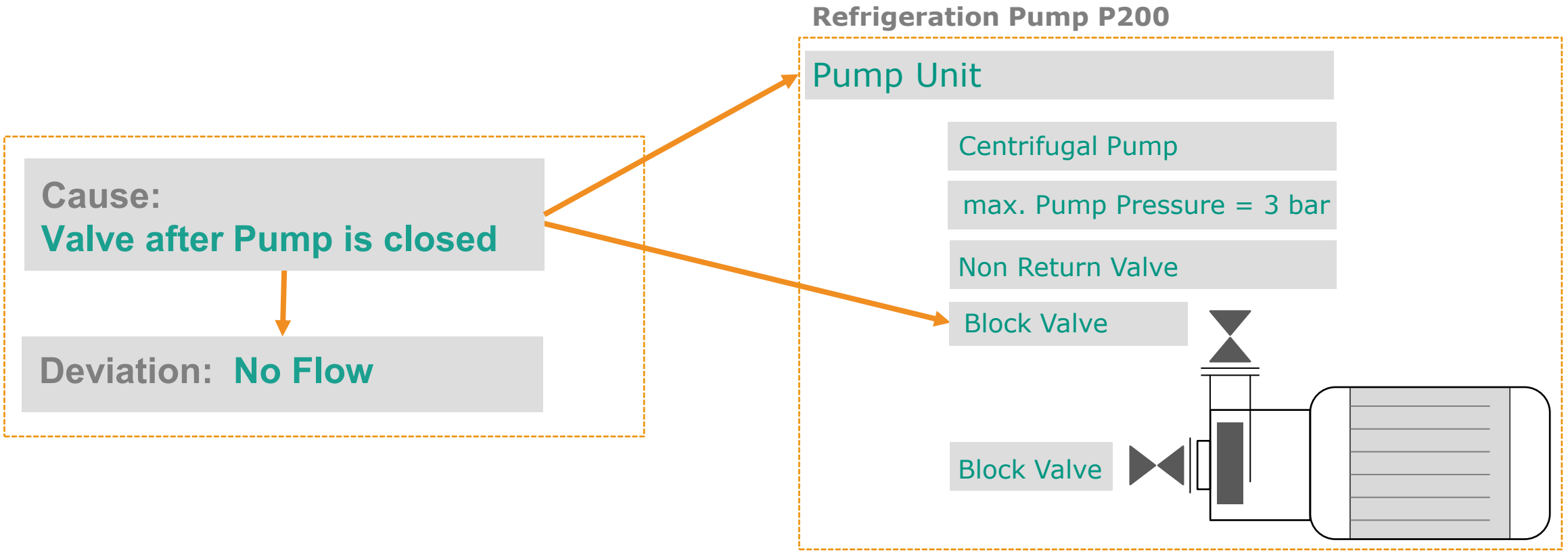
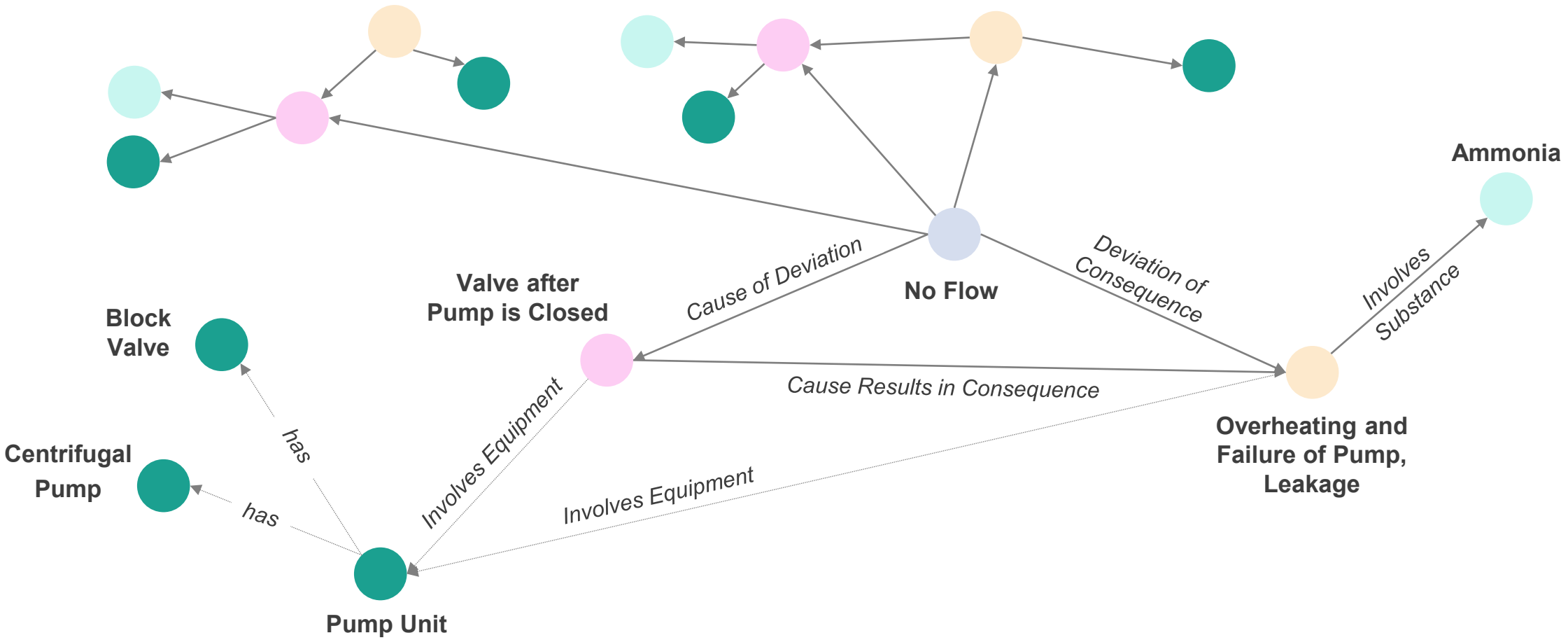
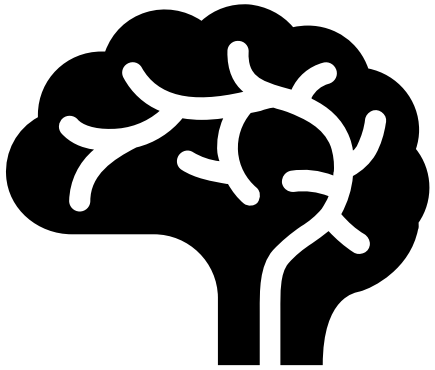


Knowledge Representation with Ontologies

- Modelling the elements HAZOP scenarios with Classes and Relations



Automated HAZOP for the Refrigeration Plant



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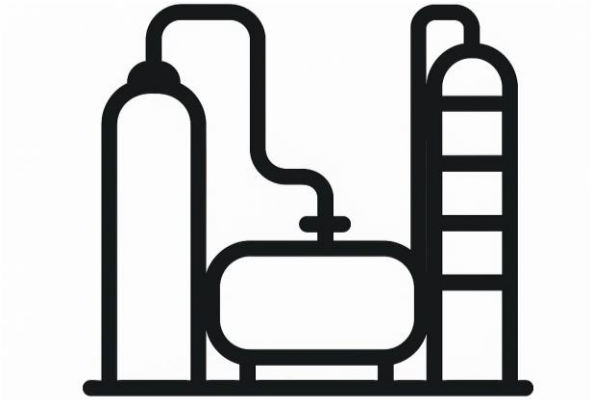
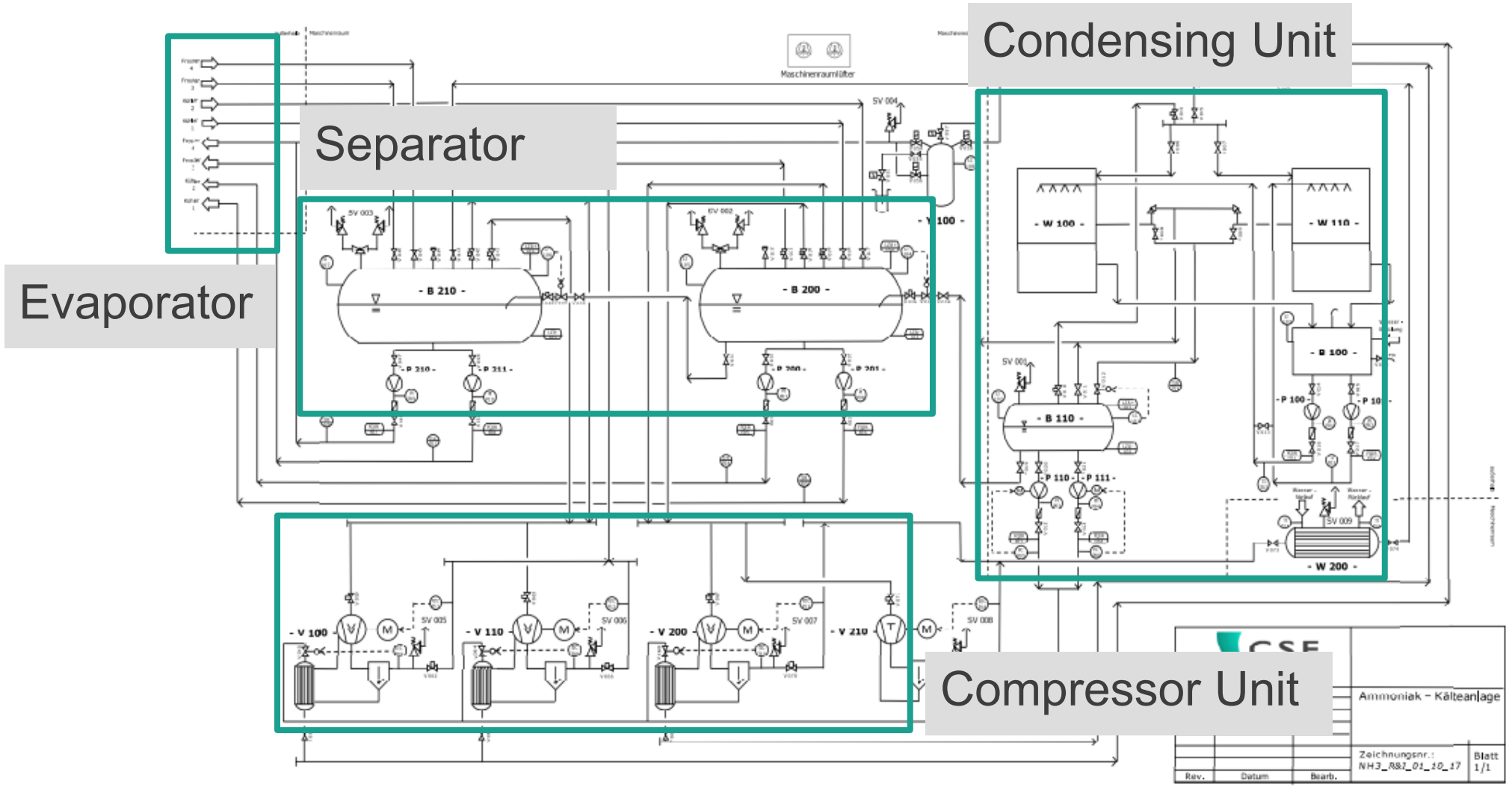


- Digital representation of the plant

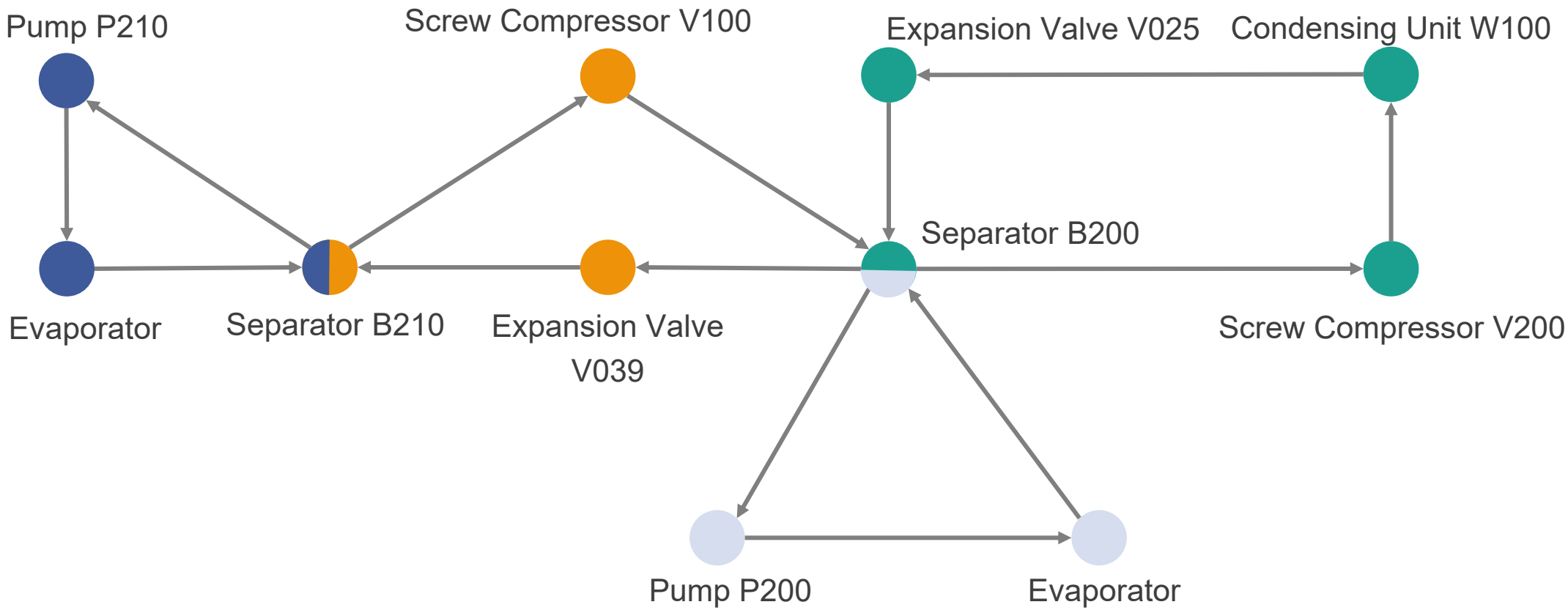
- Algorithms to identify hazardous scenarios

Digitalizing the P&ID of the Refrigeration Plant



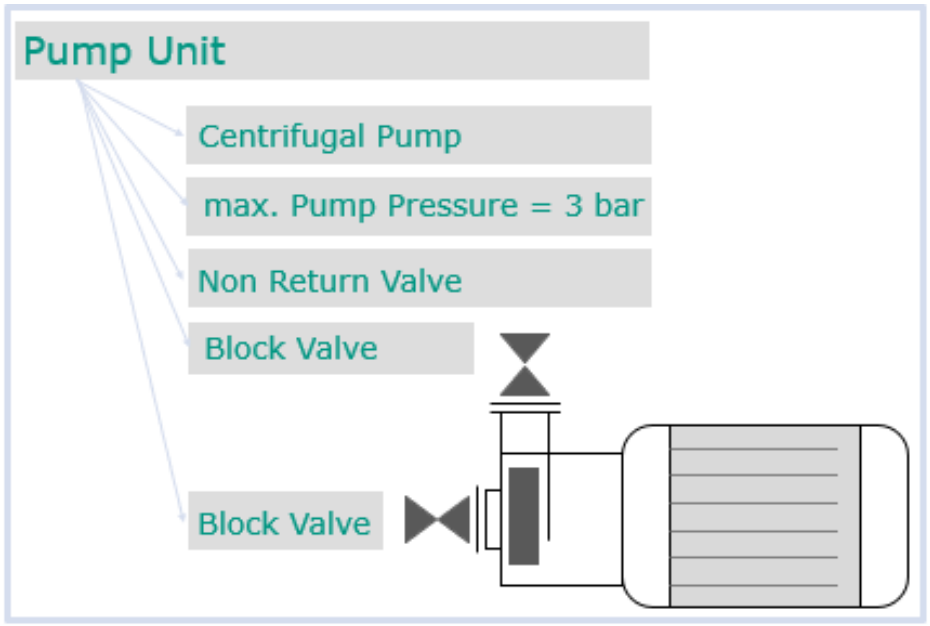
Digitalizing the P&ID of the Refrigeration Plant

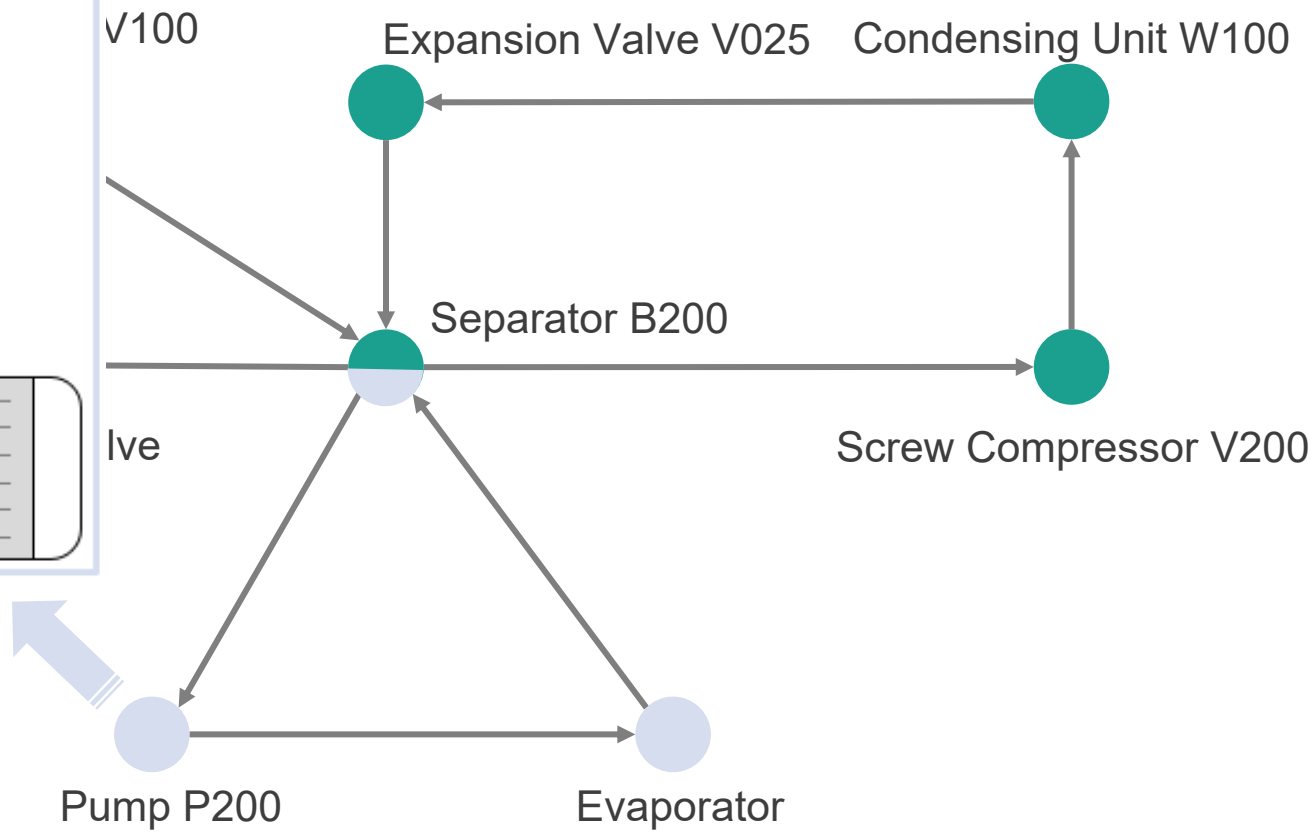
- Representing the Ammonia Refrigeration Plant as Graph



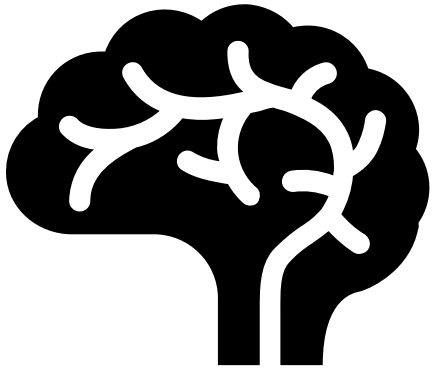
Digitalizing the P&ID of the Refrigeration Plant

- Specifying the safety-relevant Attributes of each Node





Automated HAZOP for the Refrigeration Plant



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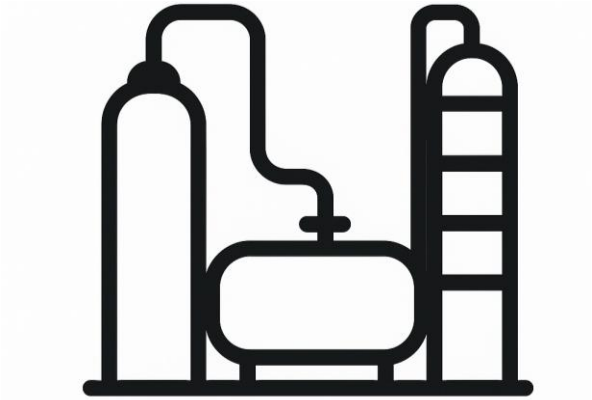

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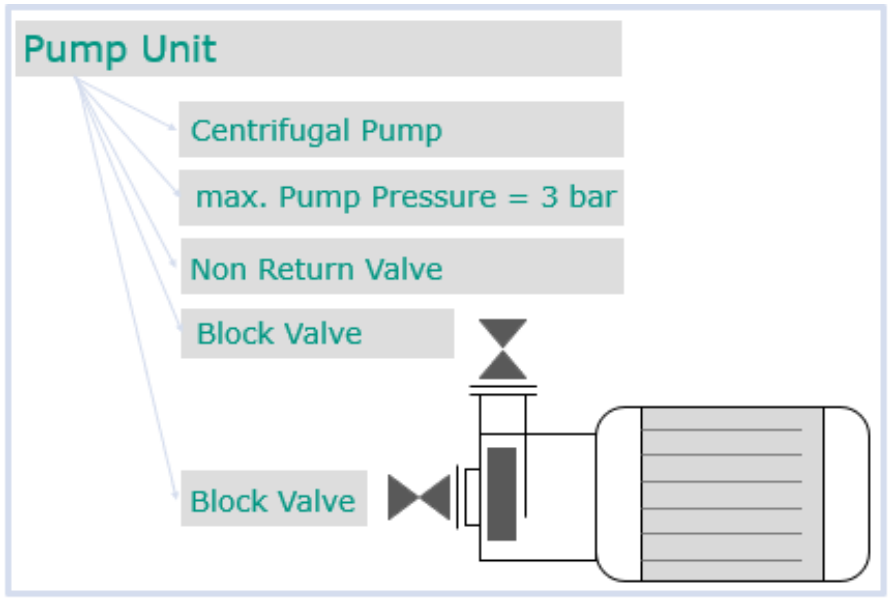
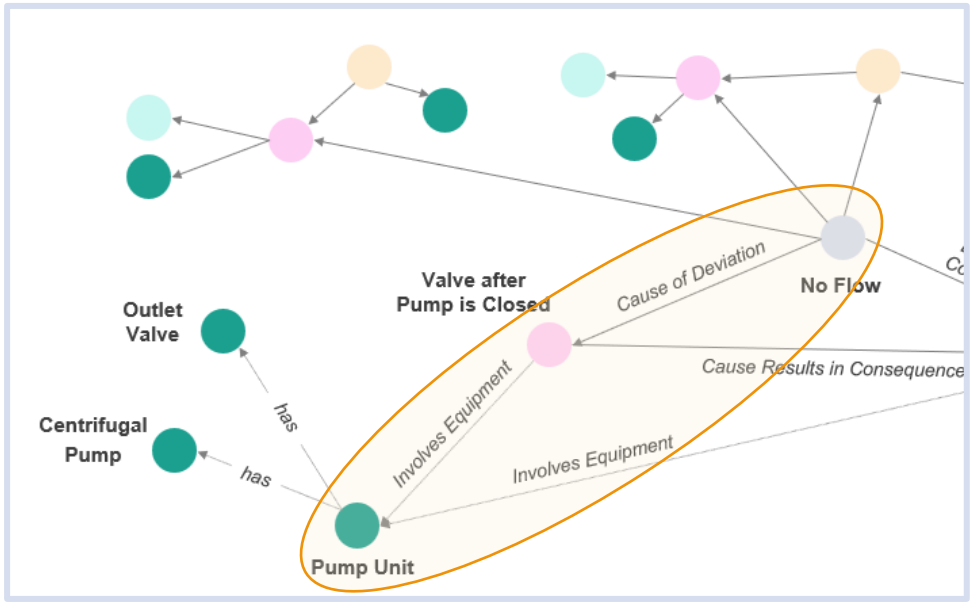
- Algorithms to identify hazardous scenarios

Equipment-based Analysis

- Equipment-based Analysis: Each Component is analyzed separately



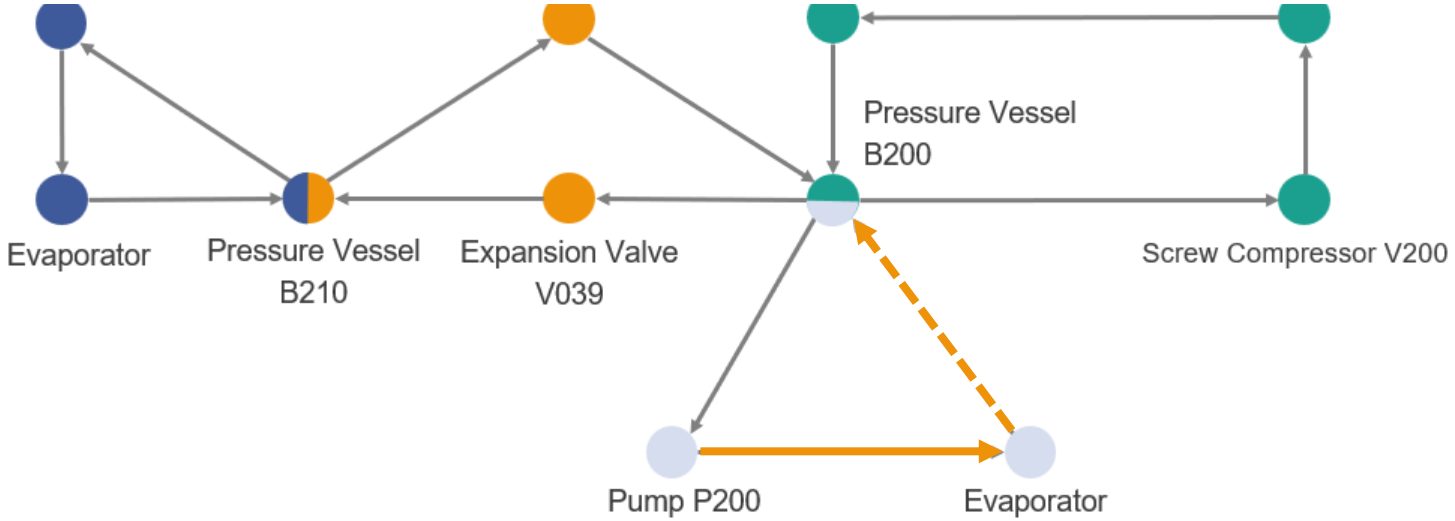


Querying the Knowledge Representation

Deviation	→	**Cause**	→	**Consequence**	→	**Safeguard**
No Flow		Outlet Valve Closed		Overheating of Pump		Valve Locked Open

Plant-based Analysis

- Plant-based Analysis: Analyzing Interactions between Components
- Propagation Strategy depends on plant Topology



Deviation: No Flow
Cause: Failure of Pump P200

Consequence
No Cooling Capacity in Evaporator

Querying the Knowledge Representation

Generating Automated HAZOP

Automated HAZOP for Refrigeration Plant

		Deviation	Cause	Consequences	Risk Class	Countermeasure
1	P200	No Flow	Operational Error – Closed Outlet Valve	Overheating – Failure of the pump – Leakage	B	No Flow Alarm, Valve Locked Open

		Deviation	Cause	Consequences	Risk Class	Countermeasure
31	V200	High Pressure	Failure in Compresser Controll Unit	Exceeding MAWP – Loss of Containment	B	High Pressure Switch

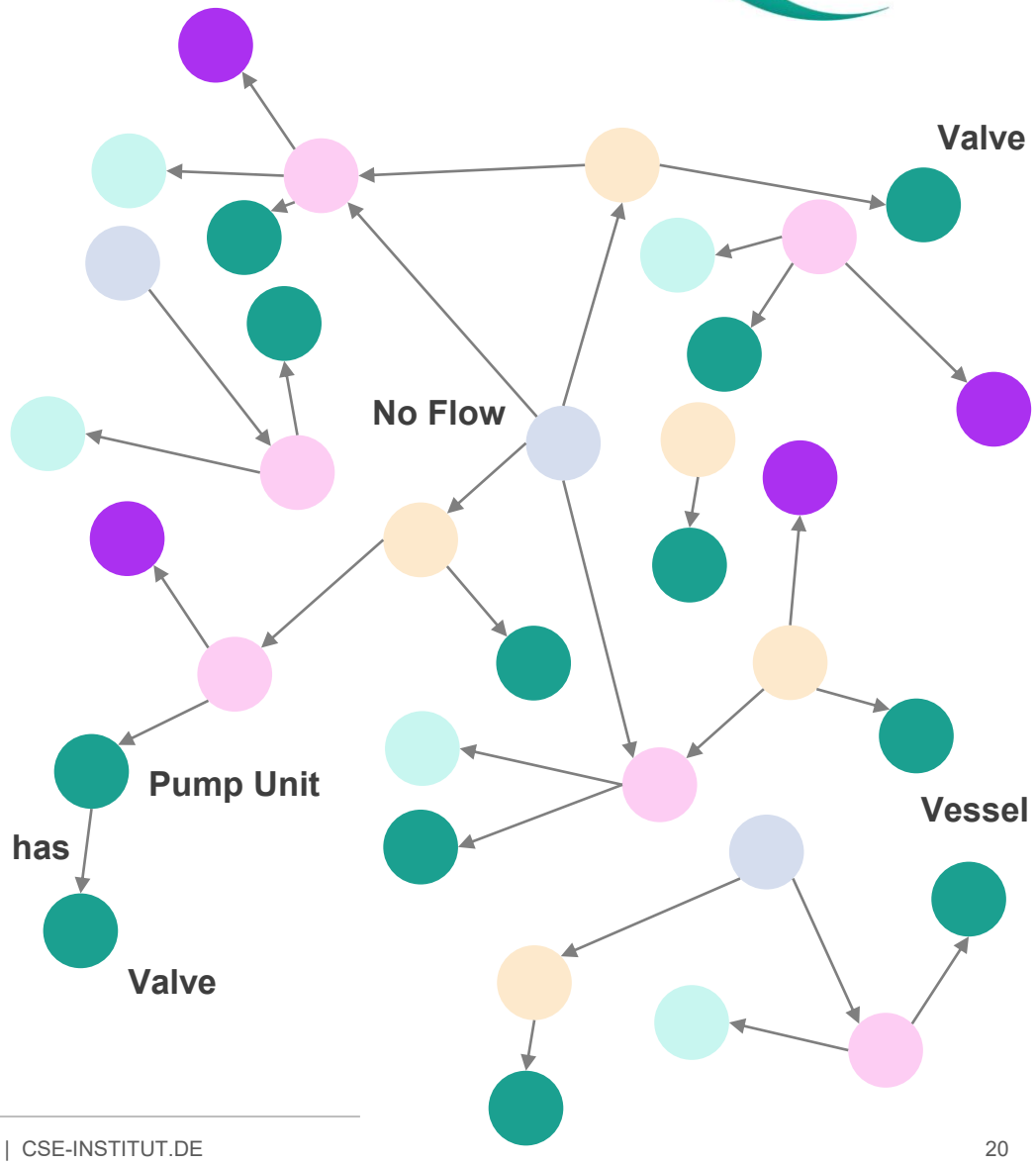
- **Completenes:** Safety relevant Scenarios found
- **Relevance**: Avoidance of redundant Szenarios
- **Reliability:** Reproducibility of Scenarios given by deterministic Method
- **Proved in further case studies:** Hexane Storage Plant, Water Separator System

Automated HAZOP for Refrigeration Plant

- Increased complexity
- Deterministic Approach
  - » Limited capability to handle novel or incomplete situations
  - » No interpreting of unstructured text data

Combining knowledge-based Approach with Large Language Models

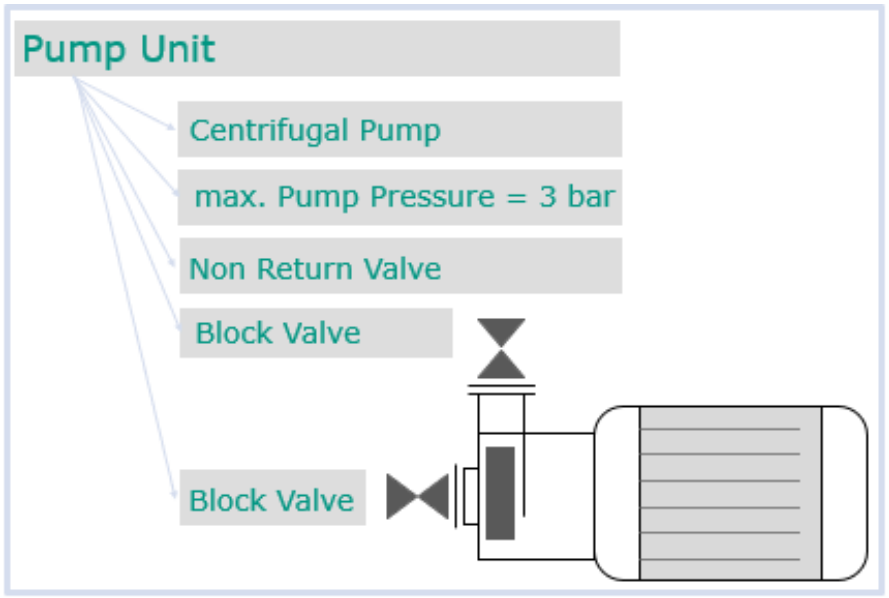
- Retrieving relevant Knowledge
- Interpreting Knowledge with LLM
- Generating HAZOP



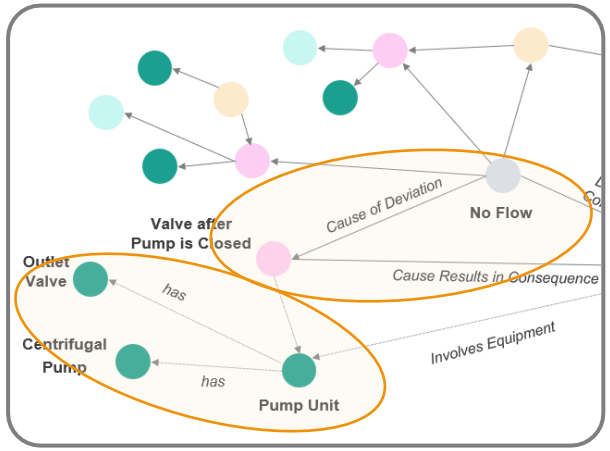
Combining Knowledge Based Approach and Large Language Models

Prompt

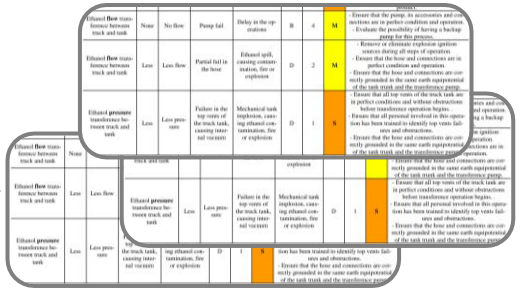
Identify the hazardous scenarios for the Ammonia Refrigeration Pump.



Retrieval



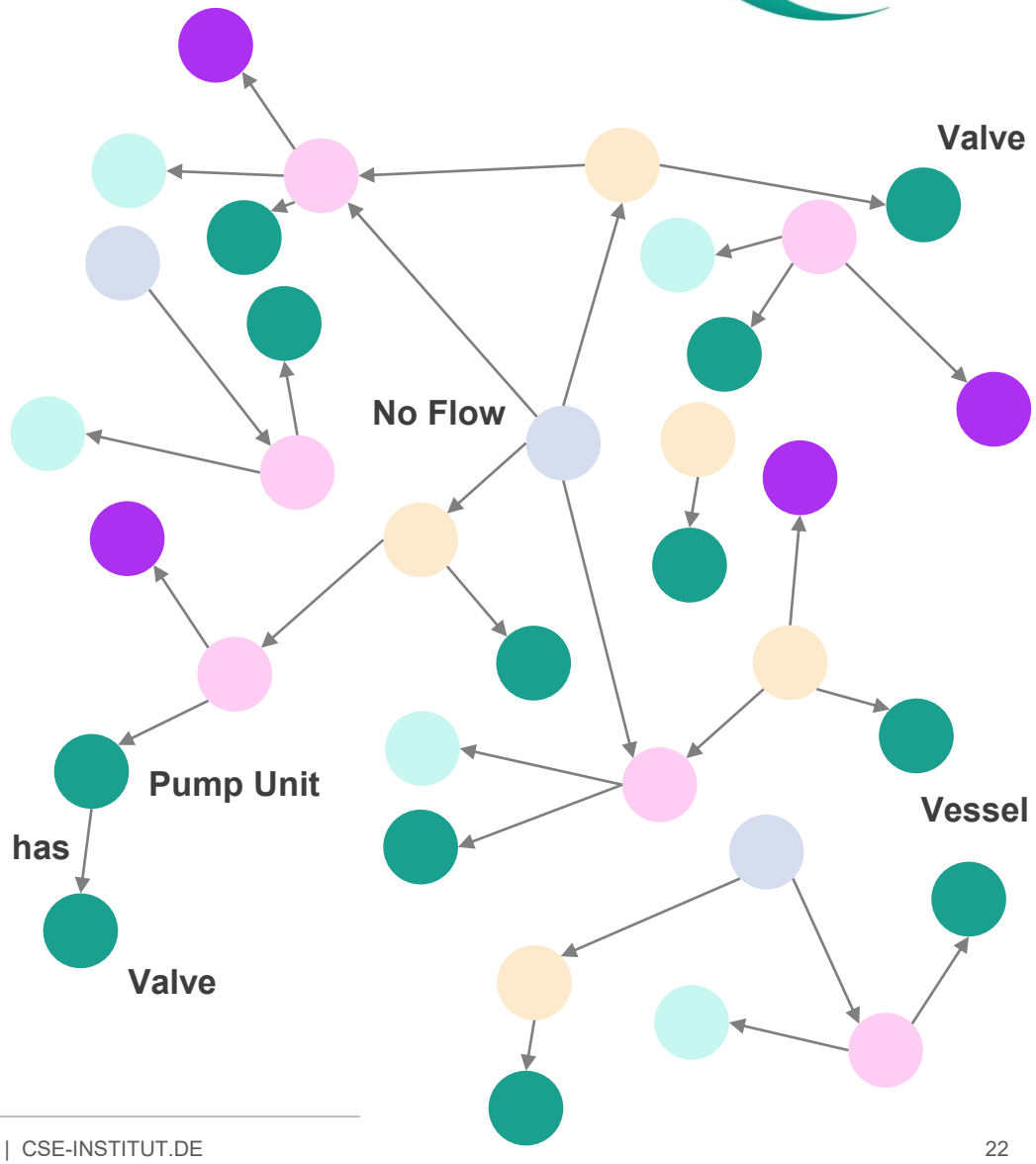
LLM



Combining Knowledge Based Approach and Large Language Models

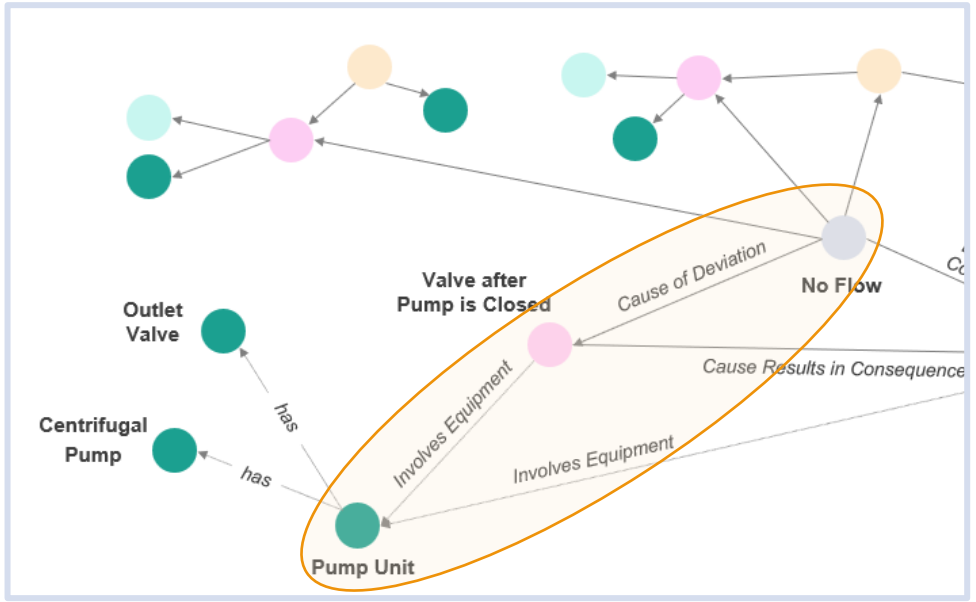
Combining knowledge representation with Large Language Models

- Better handling of new or incomplete situations
- Retrieving relevant parts of the knowledge representation instead of fixed queries
- Interpreting of text-based descriptions



Summery

- Deterministic method to automate HAZOPs
- Knowledge Representation with Ontologies
- Two-Stage Scenario Identification
  - » Equipment-based Analysis
  - » Plant-based Analysis
- Proven in various case studies
- Combining Knowledge-based Approach with Large Language Models



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Project Partner

RESEARCH AND INNOVATION IN PROCESS AND PLANT SAFETY

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