technische universität dortmund

preHAZOP: Using DEXPI P&IDs and open-source process simulation to automatically predict safety-critical plant areas

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Overview

Data preprocessing
- Why using graph data?
- How to connect plant and process data?

Results of the preHAZOP
- Fast and automated safety analysis
- Graph-based plant & process data allows machine interpretability

Motivation → Data → preHAZOP → Results → Conclusion & Outlook

Machine-readable Engineering Data
- Potential
- Accessability
- Availability

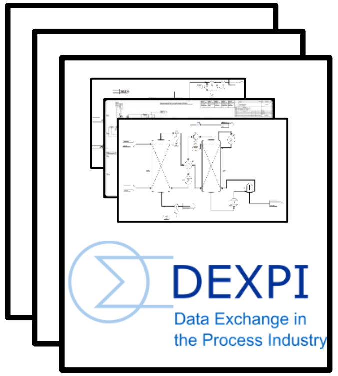
Graph-based preHAZOP
- Workflow of the preHAZOP
- How to automate safety assessments in early engineering phases?

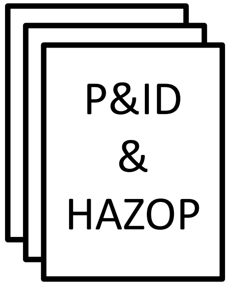
Conclusion & Outlook
- Overview - preHAZOP
- Next steps / Extensions

Motivation

- Application of AI in Process Engineering (P&IDs & Safety Analysis) needs systematic harmonization of[1]…
  - … uniform data
  - … machine readable data
  - … data, which are easy to preprocess

- Why „DEXPI“(**D**ata **EX**change in **P**rocess **I**ndustry)[2]?
  - Machine readable data topology
  - Vendor independent format
  - International standard based on Proteus XML[3]



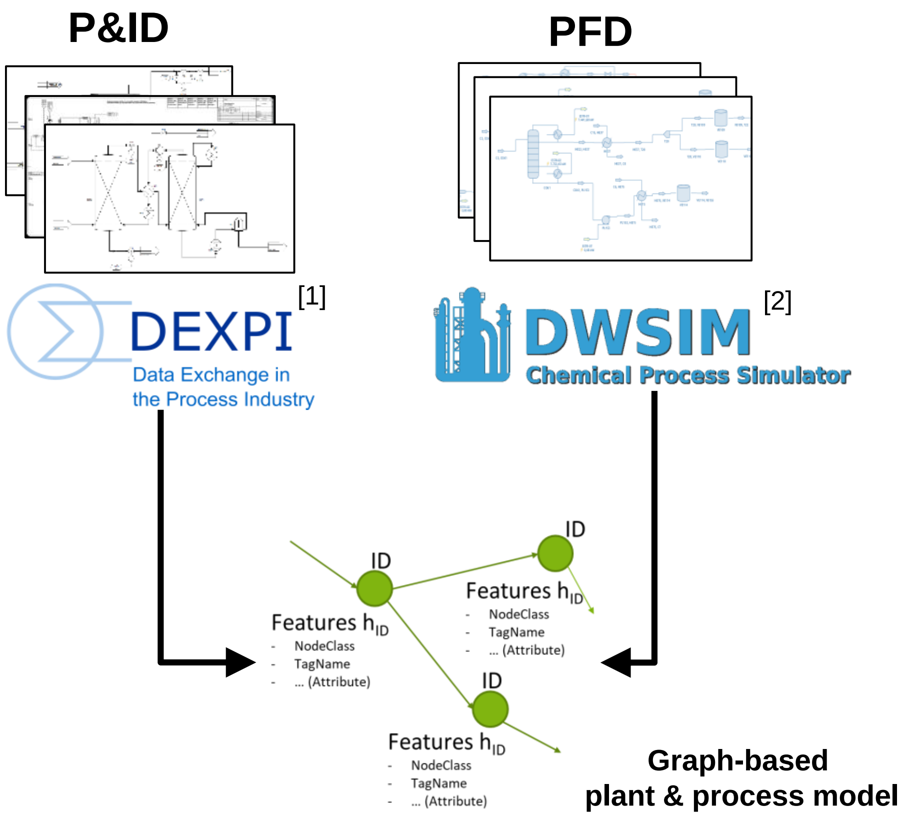


➢ Presented approaches can be used with minor adaptation for arbitrary smartP&IDs (machine-readable plant topology)

[1] M. Wiedau, et al., 2021. [2] https://dexpi.org [3] https://github.com/ProteusXML

Motivation

- Combination of plant data & process data
- Plant data
  - P&ID
  - DEXPI[1]
  - Open-/vendor independent
- Process data
  - PFD
  - DWSIM process simulator[2]
  - Open-source
- ➢ Graph-based information model (GraphML)



[1] dexpi.org, 2022 [2] dwsim.org, 2022

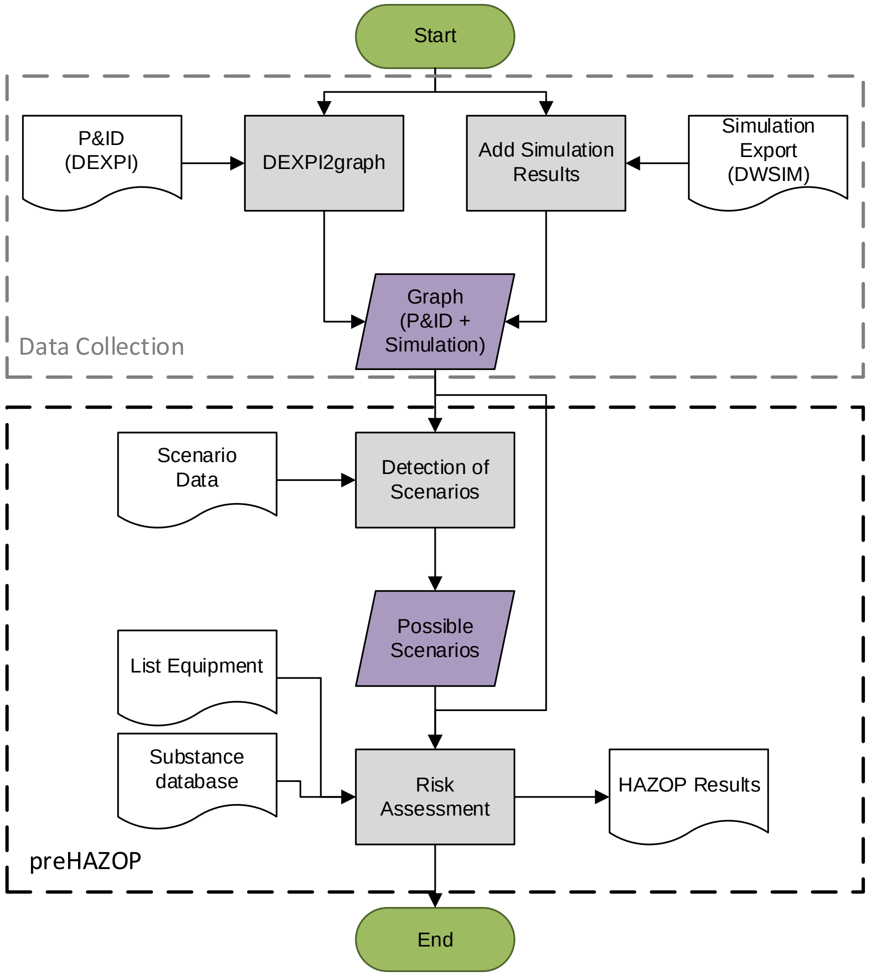
preHAZOP – Workflow

Data collection

- P&ID - DEXPI2GraphML converter[1]
- Add simulation data (DWSIM export)
- ➢ GraphML (Plant data & Process data)

preHAZOP

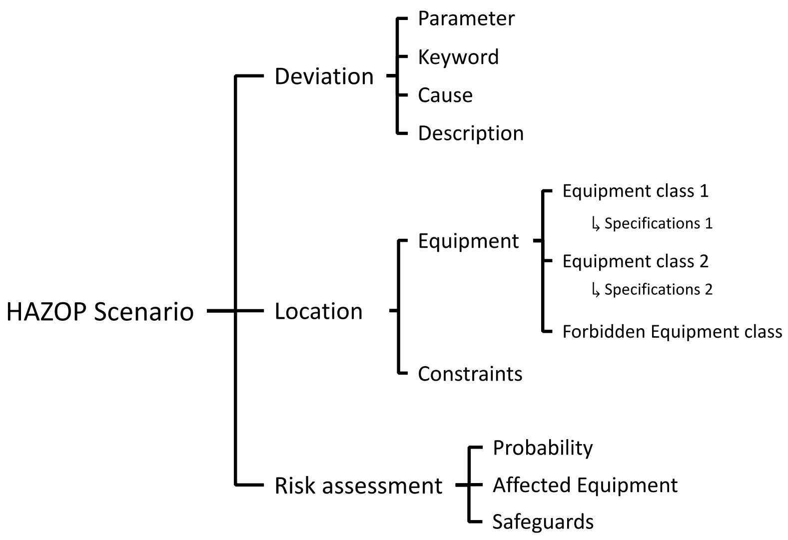
- Application of HAZOP scenarios to graph-based information model
  - Comparision with scenario data
- Automated risk assessment
  - Comparison with GHS symbols
  - Consideration of leakage volumes
  - Consideratin of the substance composition
- ➢ preHAZOP - results table



[1] https://github.com/TUDoAD/DEXPI2graphML, 2022

preHAZOP - Scenarios

- HAZOP scenario contains
  - Deviation
  - Location
  - Risk assessment
- Mapping a scenario to locations in the P&ID by iterating through a graph-based plant and process data
- Risk assessment by comparison of data in the graph and the scenario database via a risk matrix
- 15 preHAZOP scenarios predefined
  - Arbitrarily expandable dataset (Excel sheet)



Structured representation of HAZOP scenarios

Index	Description	Guideword	Parameter	Cause	Consequence	Safeguard_1	Safeguard_2	Affected Equipment	Propability	Requirements	Equipment_1	Specification_1.1
1	Pump effects vacuum cause of inert failure, resulting in vessel demolition	Lower	Pressure	Inert system failure	Damage	Pressure Low Shut down		Equipment_1	F1	Check min. operation pressure of vessel	Vessel	Inert
2	Pumping against wrongly closed valve results in damage of pump	Higher	Temperature	Valve wrongly closed	Damage	Bypass		Equipment_1	F1		Pump	
3	Pumping against closed level control valve results in damage of pump	Higher	Temperature	Valve closed by control	Damage	Bypass		Equipment_2	F1		Column	Level Control
4	Substance leaks out of pump cause of mechanical seal wear	Other	Flow	Mechanical seal wear	Seal leakage	Maintenance		Equipment_1	F1		Pump	
5	Mechanical failure of the pump	No	Rotation	Mechanical failure	Damage	Maintenance	Redundant	Equipment_1	F1		Pump	
6	Mechanical failure of the centrifuge	No	Rotation	Mechanical failure	Damage	Maintenance		Equipment_1	F1		Centrifuge	
7	Stirrer damages vessel	Other	Rotation	Mechanical failure	Damage	Maintenance		Equipment_1	F2		Vessel	Agitator
8	Cooling circiut failure leads to a higher inlet temperature, resulting in a seal leakage of vessel	Higher	Temperature	Cooling circuit fails	Seal Leakage	Inlet Temperature High Alarm		Equipment_1	F1	Compare max. operation temperature of vessel with inlet temperature	Cooler	
9	Too much heating leads to a higher inlet temperature, resulting in a seal leakage of vessel	Higher	Temperature	Too much heating	Seal Leakage	Inlet Temperature High Alarm		Equipment_1	F1	Compare max. reachable temperature with max. operation temperature of vessel	Heater	

preHAZOP - Risk assessment[1,2]

- Risk matrix
  - Estimation of severity with risk tools
  - Standardized consequences
    (“Danger“, “Seal leakage“, “Leakage“, “Rupture“)
  - Affected equipment
- Challenge: no direct access to substance databases
  - ➢ Manual input necessary
- Consequence: „Danger“
  - Financial loss (equipment cost list)
  - Financial limits

Risk matrix[1]

	S4	S3	S2	S1	S0
F0	Tolerable	High	High	High	High
F1	Tolerable	Tolerable	High	High	High
F2	Tolerable	Tolerable	High	High	High
F3	Tolerable	Tolerable	Tolerable	High	High
F4	Tolerable	Tolerable	Tolerable	Tolerable	High
F5	Tolerable	Tolerable	Tolerable	Tolerable	Tolerable

Severity estimation by financial limits

Loss	Severity
0 - 1,000 €	S4
1,000 - 10,000 €	S3
10,000 - 100,000 €	S2
100,000 - 1,000,000 €	S1
>1,000,000 €	S0

[1] IVSS Sektion Chemie, Risikobeurteilung in der Anlagensicherheit, 2020 [2] CCPS – American Institute of Chemical Engineers, Layer of protection analysis, 2001

preHAZOP - Risk assessment[1,2]

- Consequences: “Seal leakage“, “Leakage“, “Rupture“
  - Danger of substances (GHS signal word)
  - Severity estimation by leakage type
  - Severity estimation by leakage mass

➢ Greatest extent of damage (worst case)

Risk matrix

	S4	S3	S2	S1	S0
F0	Tolerable	High	High	High	High
F1	Tolerable	Tolerable	High	High	High
F2	Tolerable	Tolerable	High	High	High
F3	Tolerable	Tolerable	Tolerable	High	High
F4	Tolerable	Tolerable	Tolerable	Tolerable	High
F5	Tolerable	Tolerable	Tolerable	Tolerable	Tolerable

Severity estimation by leakage type[1]

	Seal Leakage	Leakage	Rupture
Danger	S2	S1	S0
Warning	S3	S2	S1
--	S4	S3	S2

Severity estimation by leakage mass[1]

	0 – 4.5 kg	4.5 – 45 kg	45 – 450 kg	450 – 4,500 kg	4,500 – 45,000 kg	> 45,000 kg
Danger	S3	S2	S1	S1	S0	S0
Warning	S4	S3	S2	S2	S1	S0
--	S4	S4	S4	S3	S3	S2

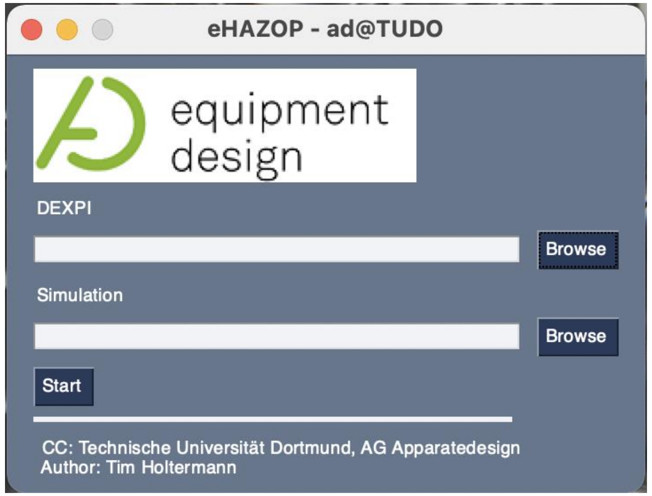
[1] IVSS Sektion Chemie, Risikobeurteilung in der Anlagensicherheit, 2020 [2] CCPS – American Institute of Chemical Engineers, Layer of protection analysis, 2001

preHAZOP – Graphical User Interface

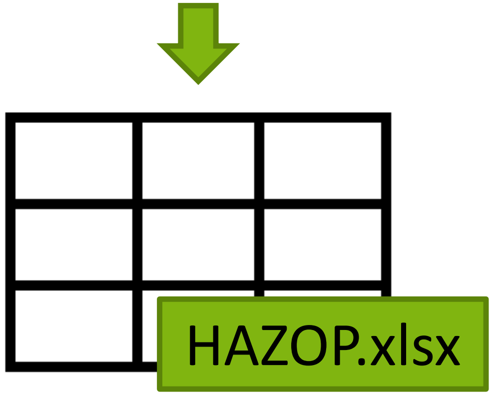
- Application using a Graphical user interface (GUI)
  - Browse DEXPI - P&ID
  - Browse DWSIM simulation export
- Python (open-source)
  - Visualization via *PysimpleGUI*[1] library
  - **Data collection** using:
    - Network analyis library – *NetworkX*[2]
  - **preHAZOP** using:
    - Graph iteration - *NetworkX*
    - Data analysis library – *pandas*[3]

➢ preHAZOP tool available on Github

➢ github.com/TUDoAD



github.com/TUDoAD

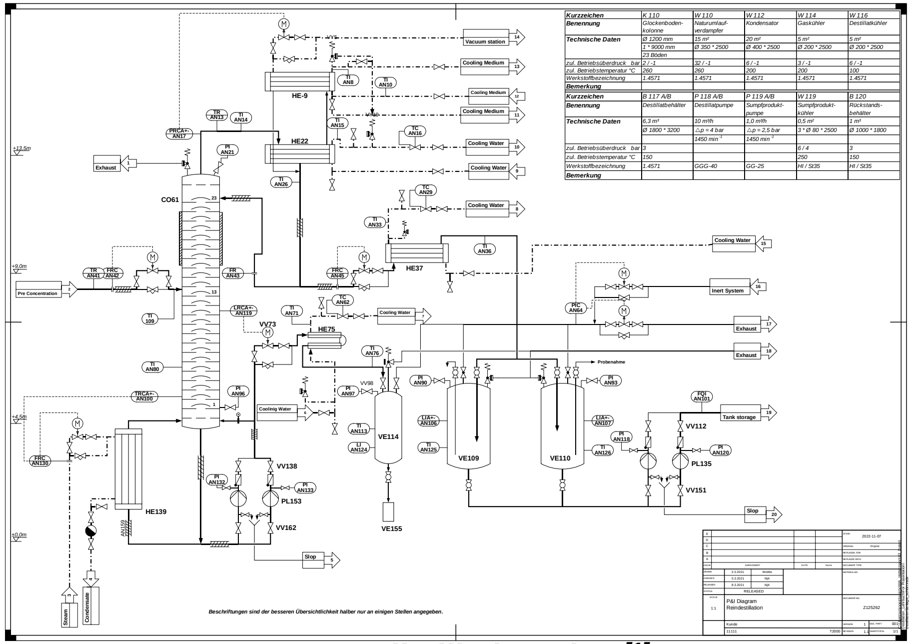


[1] pysimplegui.org, 2022 [2] networkx.org, 2022 [3] pandas.pydata.org, 2022

Results – Validation data

- **P&ID** - distillation plant[1]
  - DEXPI (PlantEngineer X-Visual)
  - 242x components
  - 269x connections (piping/signal line)

- **PFD** simulation
  - xml-Export (DWSIM)
  - Water / ethanol (50/50 wt-%)
  - 9x unit operations
  - 17x process streams



P&ID – distillation plant[1]


```xml
<?xml version="1.0" encoding="utf-8"?>
<Objects>
  <Object name="HE75, C7" type="Material Stream">
  <Object name="C6, HE75" type="Material Stream">
  <Object name="VE109, T22" type="Material Stream">
  <Object name="VE110, T22" type="Material Stream">
  <Object name="T20, VE110" type="Material Stream">
  <Object name="T20, VE109" type="Material Stream">
  <Object name="PL153, HE75" type="Material Stream">
  <Object name="VE114, VE155" type="Material Stream">
  <Object name="HE75, VE114" type="Material Stream">
  <Object name="C15, HE37" type="Material Stream">
    <Property name="Temperature" value="20" units="C" />
    <Property name="Pressure" value="1,01325" units="bar" />
```


PFD-simulation export (xml)

[1] Baerns et al., Technische Chemie, Viley-VCH, 2013

Results – preHAZOP output

- 21 critical plant areas detected automatically
  - 10 different types of scenarios
  - Output:
    - Equipment involed
    - Consequences
    - Safeguards
    - Risk

- Scenario detection based on iteration through graph-based information plant/process model reliably

- Risk assessment based on limits and substance / GHS information automated feasible

Index	Description	Deviation	Cause	Consequence	Involved Equipment	Requirements	Suggested Safeguards	Existing Safeguards	Potencial Safeguards	Substances	F	S	Risk
1.1	Pump effects vacuum cause of inert failure, resulting in vessel demolition	Lower Pressure	Inert system failure	Damage	VE109, PL135	Check min. operation pressure of vessel	Pressure Low Shut down		VE109: Safety valve, Inert system, Level Low Alarm, … // PL135: Redundant		F1	S2	High
1.2	Pump effects vacuum cause of inert failure, resulting in vessel demolition	Lower Pressure	Inert system failure	Damage	VE110, PL135	Check min. operation pressure of vessel	Pressure Low Shut down		VE110: Safety valve, Inert system, Level Low Alarm, … // PL135: Redundant		F1	S2	High
2.1	Pumping against wrongly closed valve results in damage of pump	Higher Temperature	Valve wrongly closed	Damage	PL153, VV138		Bypass		PL153: Redundant		F1	S3	Tolerable
2.2	Pumping against wrongly closed valve results in damage of pump	Higher Temperature	Valve wrongly closed	Damage	PL135, VV112		Bypass		PL135: Redundant		F1	S3	Tolerable
3.1	Pumping against closed level control valve results in damage of pump	Higher Temperature	Valve closed by control	Damage	CO61, PL153, VV73		Bypass	Bypass (VV73)	CO61: Safety valve, Outlet Pressure Low Alarm, … // PL153: Redundant// VV73: Level Control		F1	S3	Tolerable
4.1	Substance leaks out of pump cause of mechanical seal wear	Other Flow	Mechanical seal wear	Seal leakage	PL153		Maintenance		PL153: Redundant	Water	F1	S4	Tolerable
4.2	Substance leaks out of pump cause of mechanical seal wear	Other Flow	Mechanical seal wear	Seal leakage	PL135		Maintenance		PL135: Redundant	Ethanol, Water	F1	S1	High
5.1	Mechanical failure of the pump	No Rotation	Mechanical failure	Damage	PL153		Maintenance, Redundant	Redundant (PL153)	PL153: Redundant		F1	S3	Tolerable
5.2	Mechanical failure of the pump	No Rotation	Mechanical failure	Damage	PL135		Maintenance, Redundant	Redundant (PL135)	PL135: Redundant		F1	S3	Tolerable
8.1	Cooling circiut failure leads to a higher inlet temperature, resulting in a seal leakage of vessel	Higher Temperature	Cooling circuit fails	Seal Leakage	HE37, VE109	Check max. operation temperature of vessel	Inlet Temperature High Alarm		HE37: Safety valve, Inlet Flow Control, … // VE109: Safety valve, Inert system, …	Ethanol, Water	F1	S1	High
8.2	Cooling circiut failure leads to a higher inlet temperature, resulting in a seal leakage of vessel	Higher Temperature	Cooling circuit fails	Seal Leakage	HE37, VE110	Check max. operation temperature of vessel	Inlet Temperature High Alarm		HE37: Safety valve, Inlet Flow Control, …// VE110: Safety valve, Inert system, …	Ethanol, Water	F1	S1	High
8.3	Cooling circiut failure leads to a higher inlet temperature, resulting in a seal leakage of vessel	Higher Temperature	Cooling circuit fails	Seal Leakage	HE75, VE114	Check max. operation temperature of vessel	Inlet Temperature High Alarm		VE114: Safety valve, Inert system, Outlet Pressure Control	Water	F1	S4	Tolerable
10.1	Pump is turned on when there is no medium in vessel, so it runs dry	No Flow	Wrongly turned on	Damage	VE109, PL135			Level Low Alarm (VE109)	VE109: Safety valve, Inert system, Level Low Alarm, … // PL135: Redundant		F1	S3	Tolerable
…	…	…	…	…	…	…	…	…	…	…	…	…	…

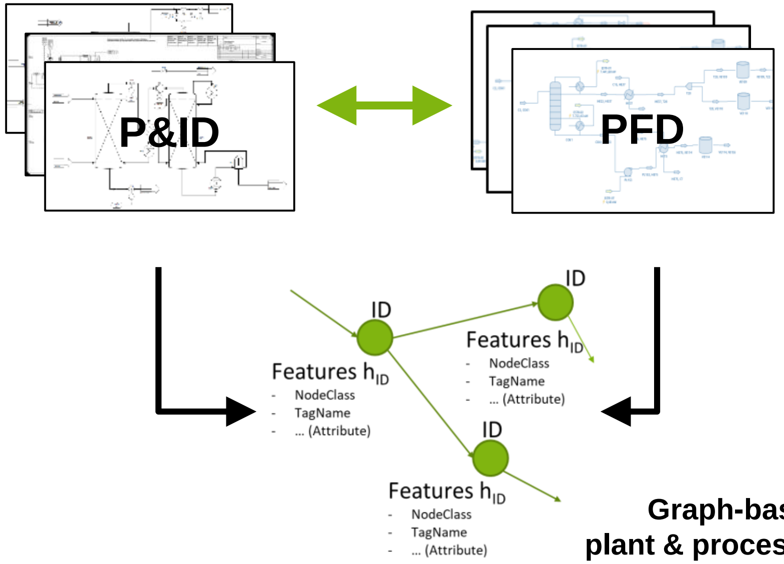
preHAZOP results

<u>Future Work:</u> Ontology-based Linking of PFD & P&ID

- Ontology to connect PFD data & P&ID data in a knowledge graph
- Use cases:
  - Build PFD simulation from P&ID with minimal amount of additional data
  - P&ID generation based on PFD simulation
  - Connect basic engineering and detail engineering

➢ More efficient data exchange between P&ID and PFD
➢ Lower error susceptibility during merging
➢ Class-based knowledge allows integration of further ontologies (e.g. chemical database – ChEBI)

Ontology
P&ID ↔ PFD



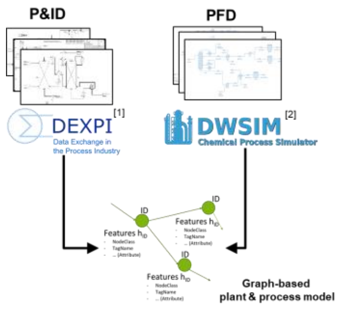
Graph-based plant & process model

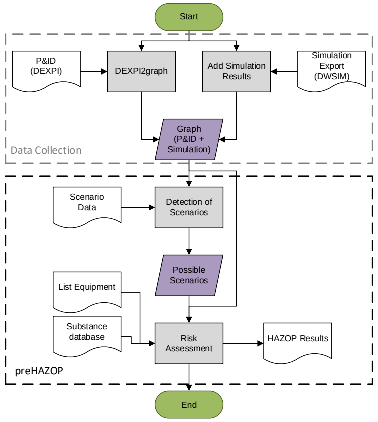
Conclusion & Outlook

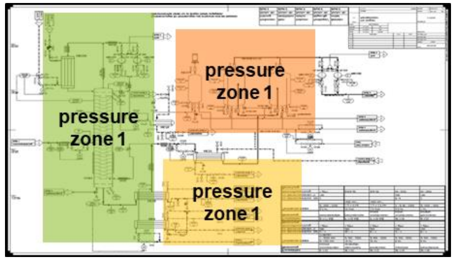
- Workflow: preHAZOP
  - Preprocessing: Linking plant topology & process data
  - Automated safety assessment in early engineering phases

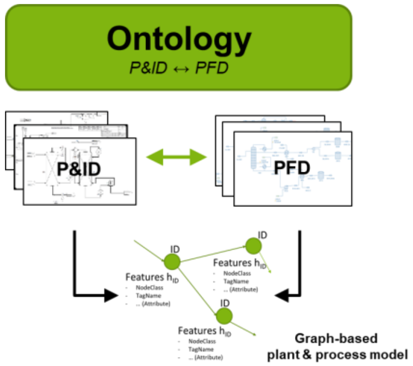
- Validation: preHAZOP
  - Distillation plant (ethanol/water)

- Outlook:
  - Extension of the preHAZOP by pressure zones
    - Application of the scenario detection to pressure zones
  - Ontology-based Linking of PFD & P&ID
    - Semantic connection of basic and detail engineering data
  - Implementation in P&ID software (X-Visual Technologies GmbH)









Thank you for your attention

KEEN platform

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Acknowledgments

DLR Projektträger

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