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From Machine Learning to Machine Reasoning: A Model-Based System Engineering Perspective

May 2024

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Changing the World's Energy Future

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LWRS
LIGHT WATER REACTOR SUSTAINABILITY

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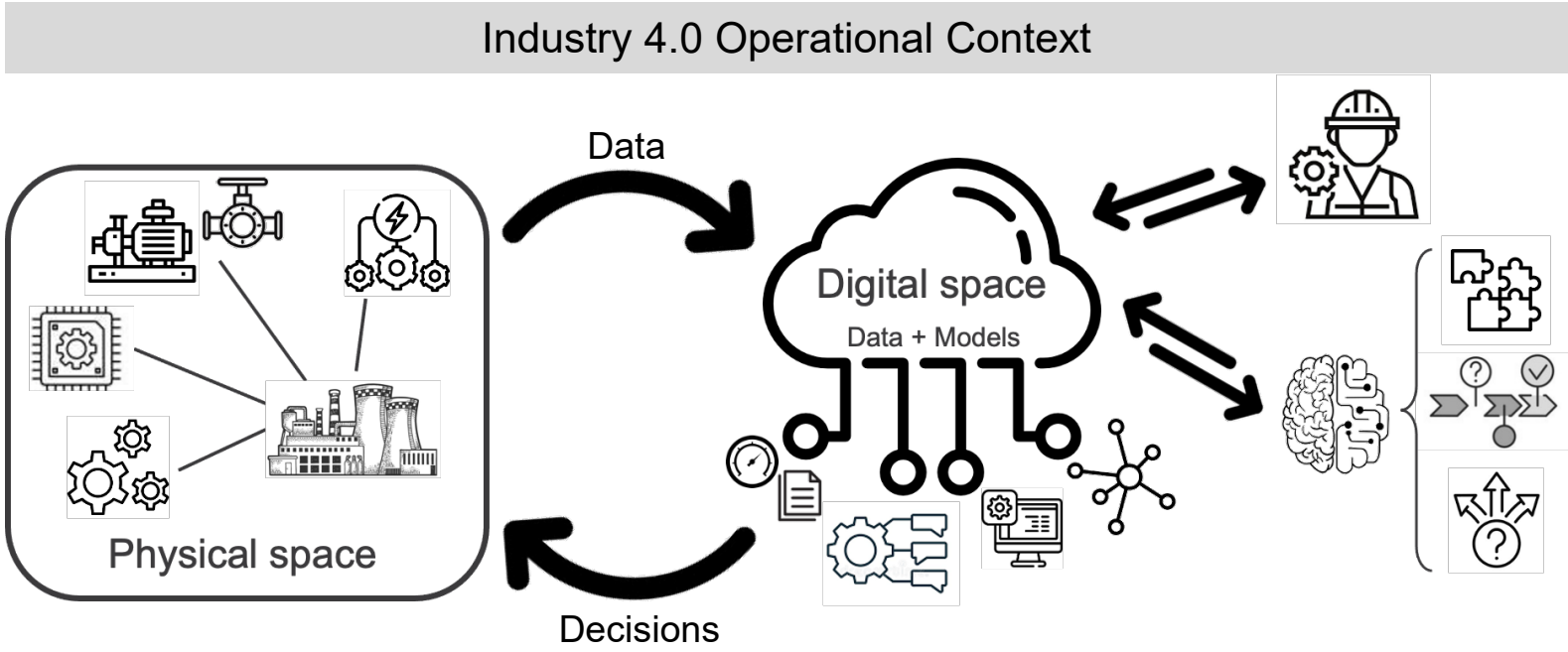
This Talk: Performance, Data, and Decisions

- Focus of this talk: Creating a direct link between data and decisions through data analytics methods
- Application: Nuclear power plants
- Claim: Pure data-centric methods do not support robust and resilient decisions
- Challenge: Provide context to available data
  - Machine reasoning requires such context
  - MBSE models can be a solution

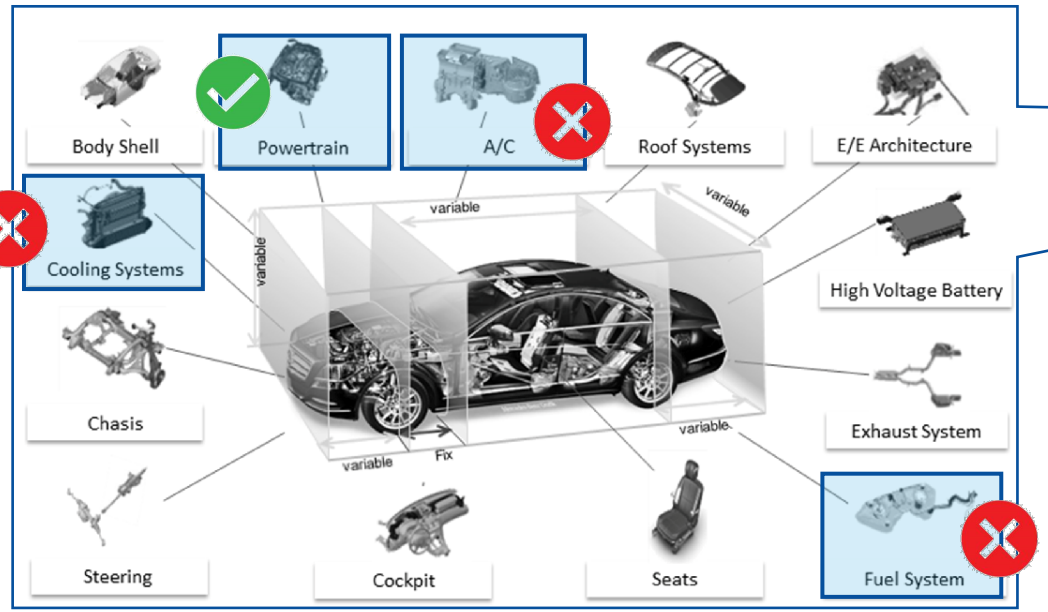


An Intuitive Example

Asset

Data

Abnormal event



Check

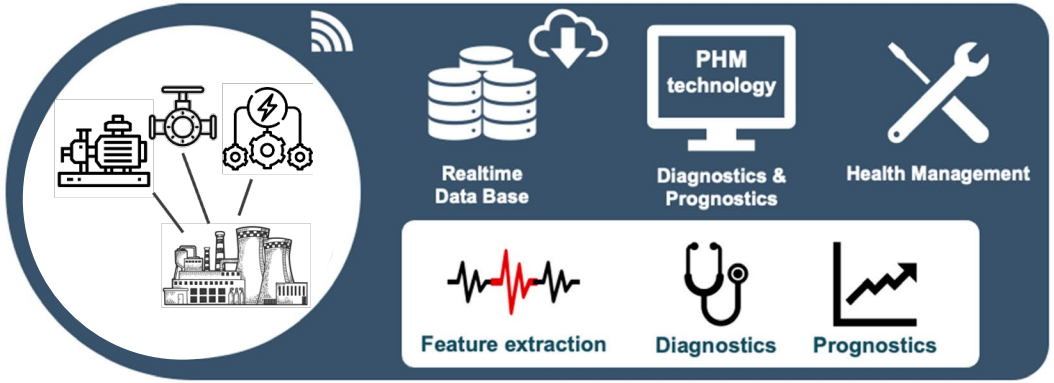
Fix

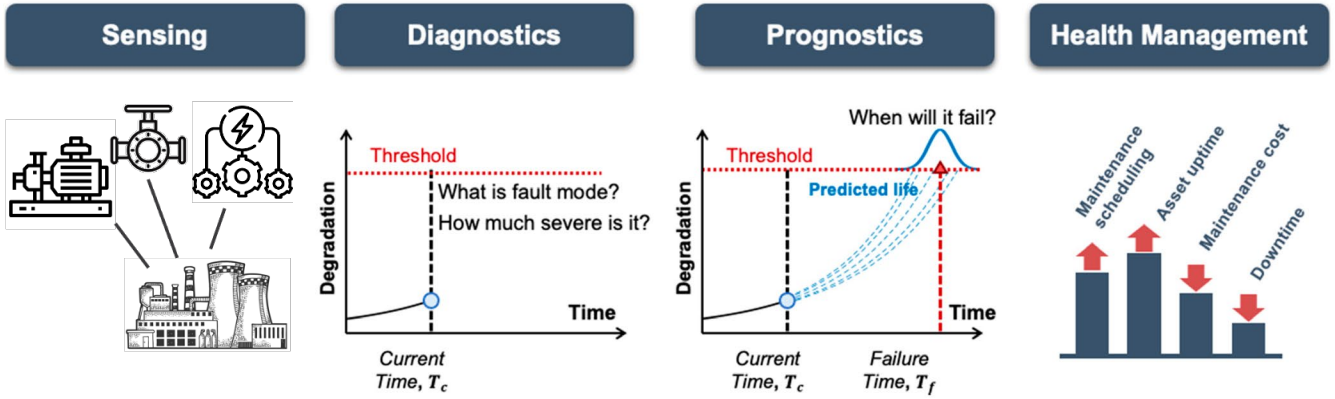
Restore

Record

Data and Decisions

- **Data:** Nuclear power plants collect large amounts of data elements
  - Record health performance throughout the lifecycle of assets
  - Can provide system engineers with insights into
    - Anomalous behaviors or degradation trends
    - Possible causes and their direct consequences
  - Data formats
    - Numeric: online monitoring data (e.g., pump vibration data)
    - Textual: issue reports and maintenance reports
  - Need to integrate information contained in numeric and textual data elements
- **Decisions**
  - Adapt to evolving operational conditions
    - Discover and counteract abnormal behaviors
  - Automate decision process



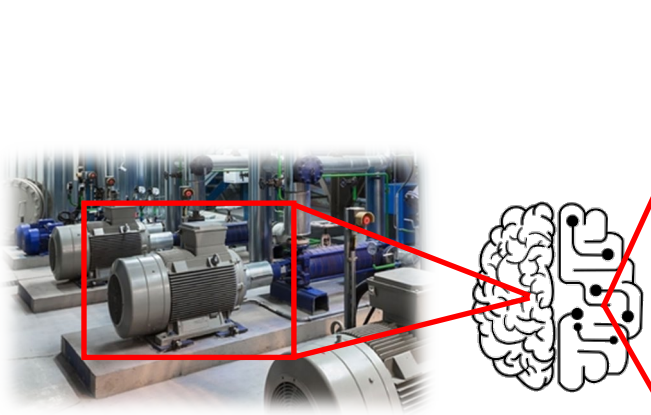


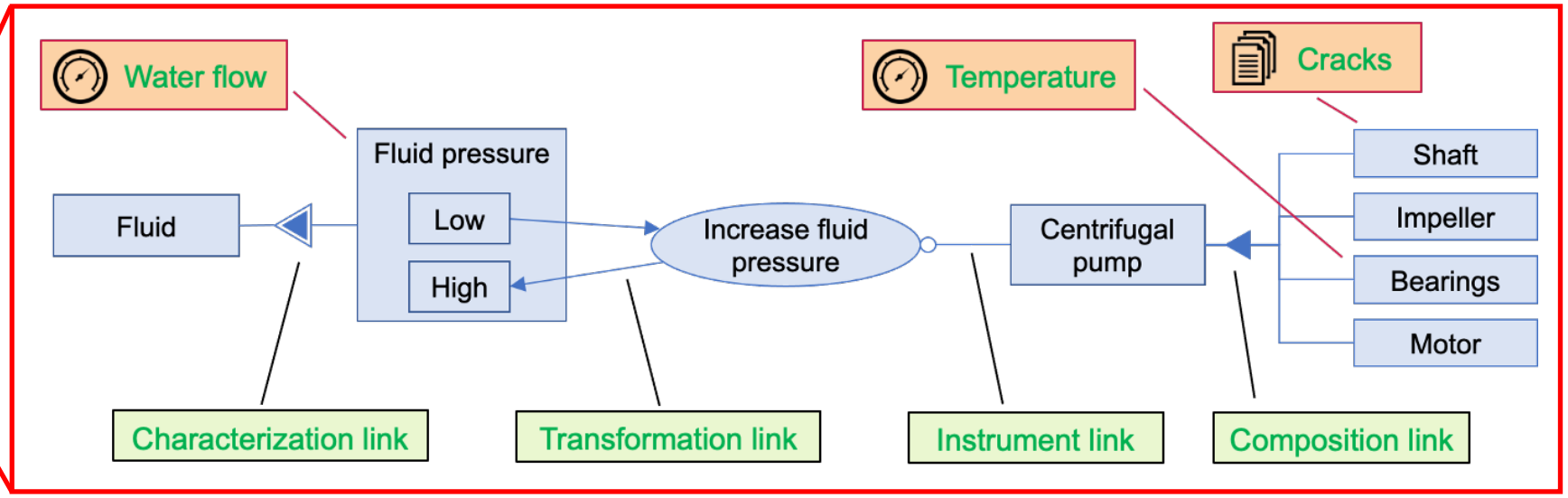
Adapted from: Kim S, Choi J-H, Kim NH. Challenges and Opportunities of System-Level Prognostics. *Sensors*. 2021; 21(22):7655. https://doi.org/10.3390/s21227655

Putting Data into Context

Data is not enough!

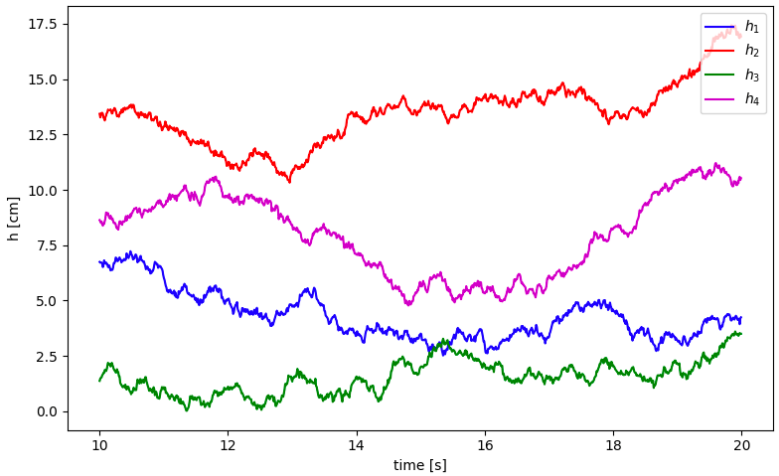
- Need to emulate system engineer knowledge about assets and systems
- Solution: Model-Based System Engineering (MBSE) diagram-based representation
  - Identify causal links between “Form” and ”Function” elements
  - MBSE languages: Object Process Methodology (OPM), Lifecycle Modeling Language (LML)
- Link between MBSE models and data can be established
- Machining reasoning: Identify logical links between data elements through MBSE models





Analysis of Numeric Data

- Model centric approach to data analytics: Based on causal inference
- Goal: Extract causal information among observed variables
  - Discover and quantify causal relations among observed data
  - Data translated in graphs: Structural causal models

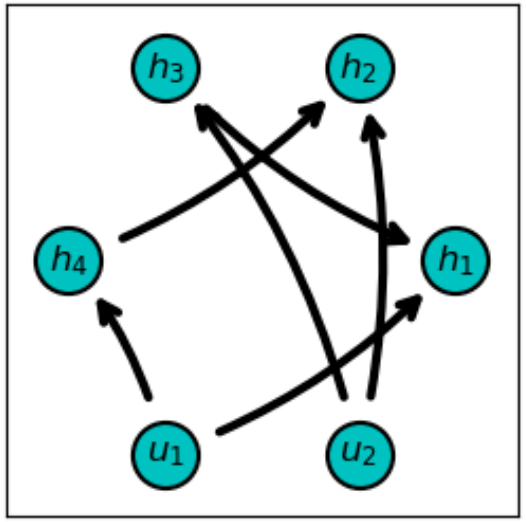


Def. Cause-Effect Relation (A→B).
A physical phenomena such that
a change in A leads to a change in B

Statistical conditional independence testing

Statistical regression modeling

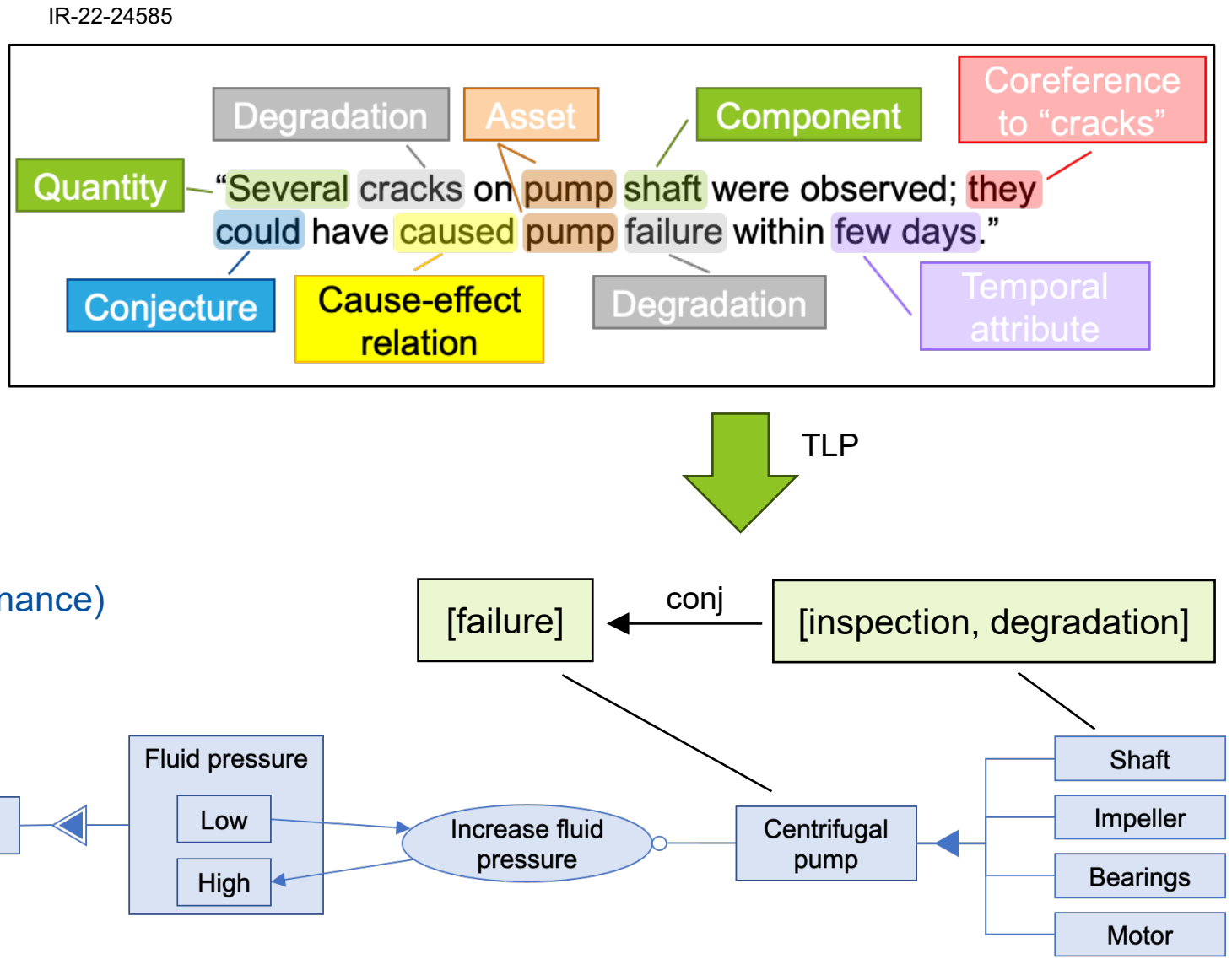
Causal inference



- Focus on the relations between variables rather rather than the variables themselves
- MBSE models are used to inform the process of causal discovery
- Applications
  - Formulate control profiles
  - Anomaly detection
  - Test hypotheses (e.g., missing edge has emerged)

Analysis of Textual Data

- Technical Language Processing (TLP) methods
  - From text to knowledge
- Developed functionalities
  - Spell check and abbreviation handling
  - Identification
    - Nuclear related keywords
    - Temporal and location attributes
    - Measured quantities
  - Assessment reported event
    - Event nature (e.g., inspection, maintenance)
    - Component health assessment
    - Cause-effect relations
  - Link data to MBSE model entities



Capturing System Knowledge

- Knowledge is stored in the form of a graph (relational database): MBSE graphs are the underlying skeleton
- Data elements are associated and linked to specific MBSE entities
  - Data is put into an MBSE context
- Knowledge graph captures system architecture and data
- Machine reasoning: Identification of causal relationships between data elements
  - Requires two conditions: logical and temporal

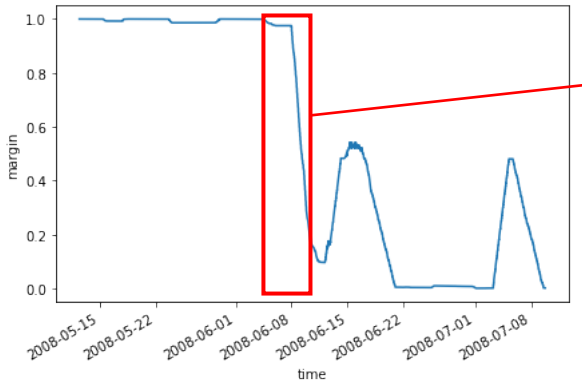
SCR #: D-204

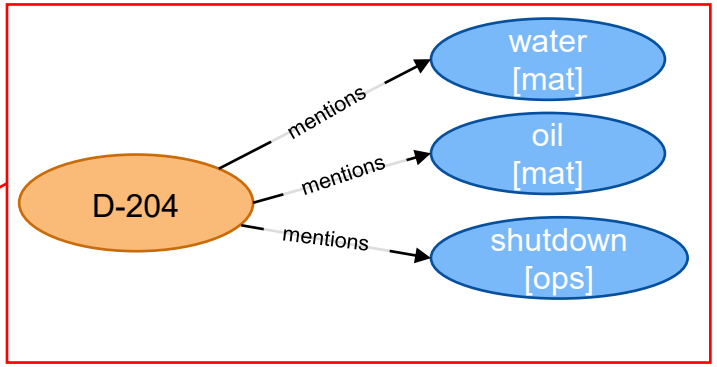
1-20-PM1 was discovered to have water/oil mixture in sight glass. Pump was shutdown.

TLP

MBSE-based graph
(system architecture)

Anomaly association to knowledge graph





Textual data association to knowledge graph

Final Considerations

- **Advanced data analytics methods**
  - Extracting knowledge from textual data
  - Quantifying asset behaviors through causal inference
  - Summarize system performance in an MBSE-based knowledge graph

- State of the art data analytics methods can be used to support plant operations
  - **Industry 4.0 mindset**

- **New roles of system engineers**
  - *Data*: Assess how data reflects known phenomena
  - *Methods*: Assess performance of data analytics methods
  - *Decisions*: Assess how decision making reflects the outcomes generated by data analytics methods