

Discovery through process data analytics

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Imperial College London

Nordic Process Control Award Lecture
August 22nd 2019

at the 22nd Nordic Process Control Workshop, Technical University of Denmark

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- REAL-SMART Project
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- Centre for Process Systems Eng
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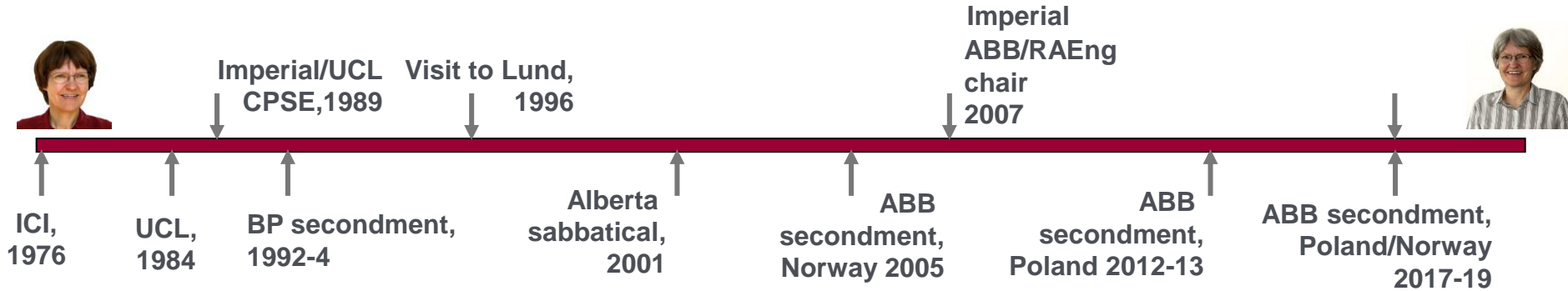
Agenda

- Introduction and personal history
- Process data analysis – Thornhill's way
- Plant-wide disturbances in an oil platform
- Data analytics in autonomous operation
- Observations for younger generations

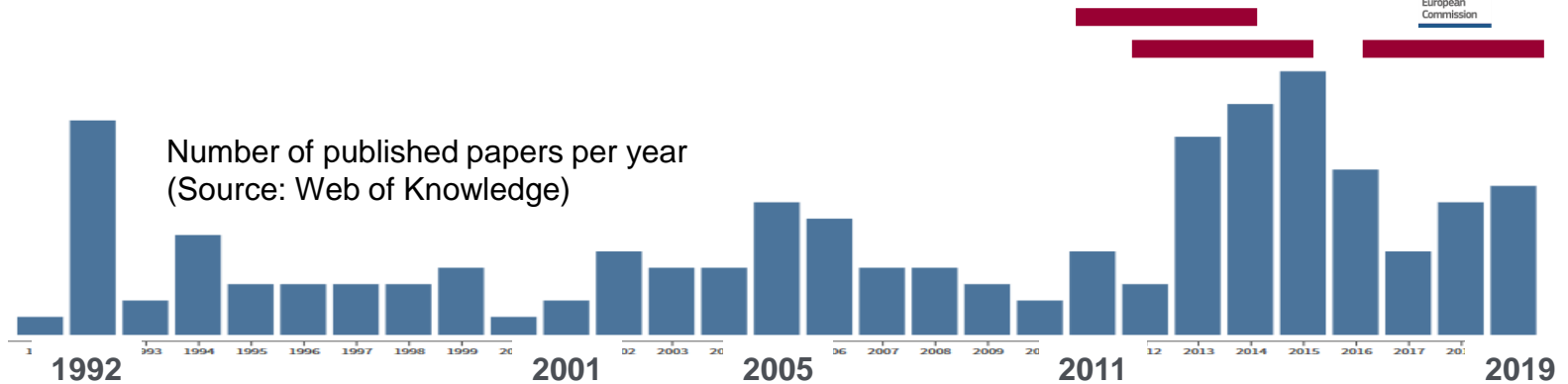
Introduction and personal history

- The specification for the lecture
 - Reflecting on scientific expertise and contributions (in retrospect)
 - Sharing perspectives for future of the field
 - Sharing social or personal anecdotes/experiences
 - Motivating and inspiring the young generation

Introduction and personal history



Marie Skłodowska Curie EU projects



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What have Thornhill and co-workers have done for ...

Controller performance

Data signatures

Visualization

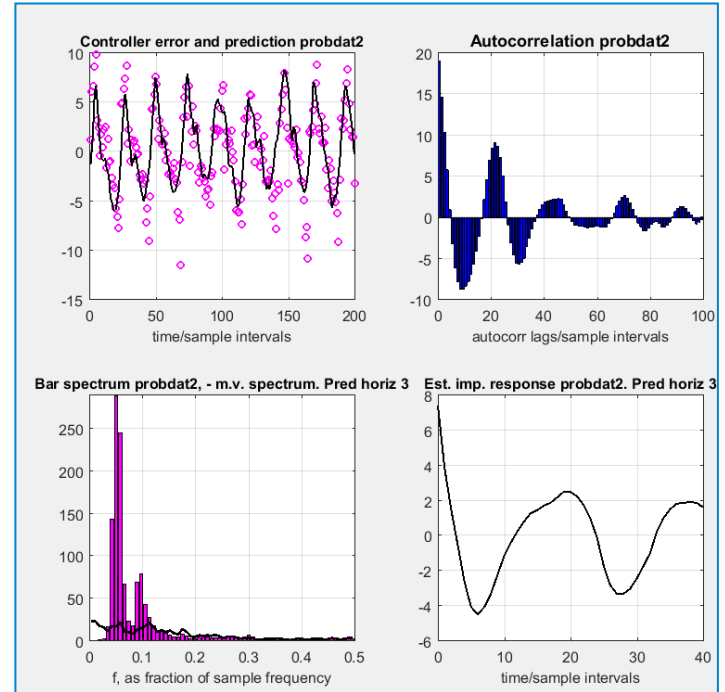
Plant-wide approaches

Root cause analysis

Plant understanding

Process data analysis – Thornhill's way

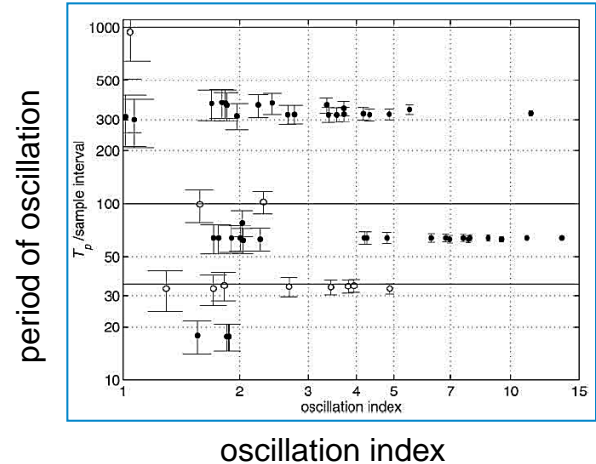
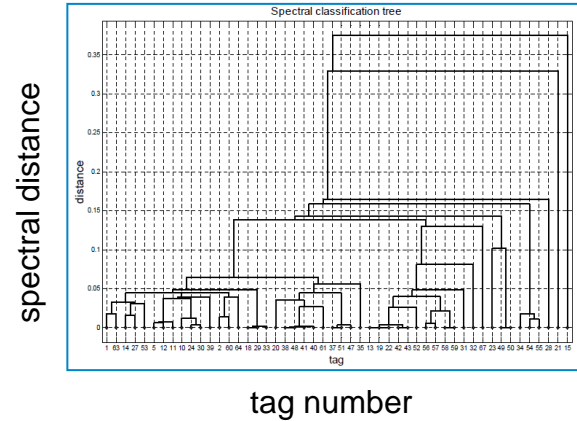
- Control loop performance assessment
 - with BP colleagues



controller performance

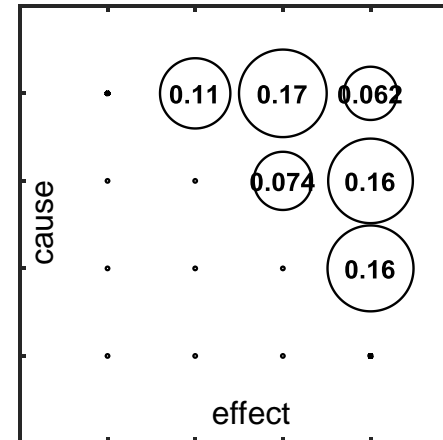
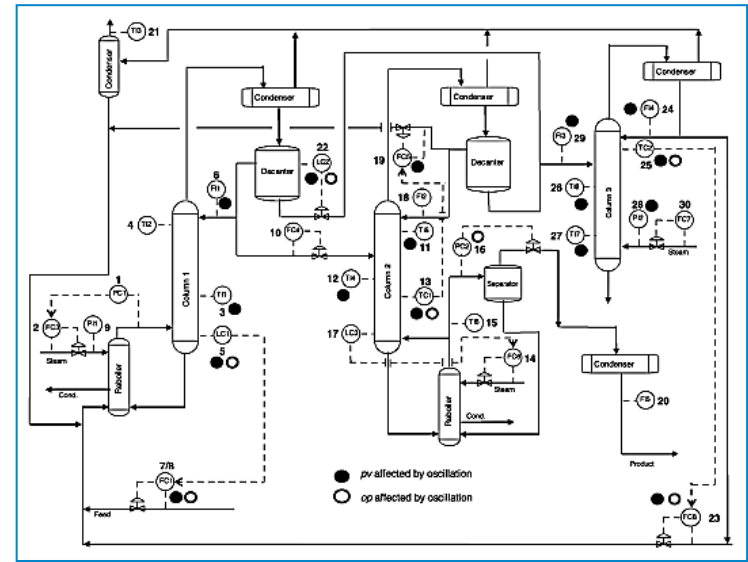
Process data analysis – Thornhill's way

- Oscillation detection
 - with Tore Hagglund
- Plant-wide oscillation detection
 - with Biao Huang and Sirish Shah



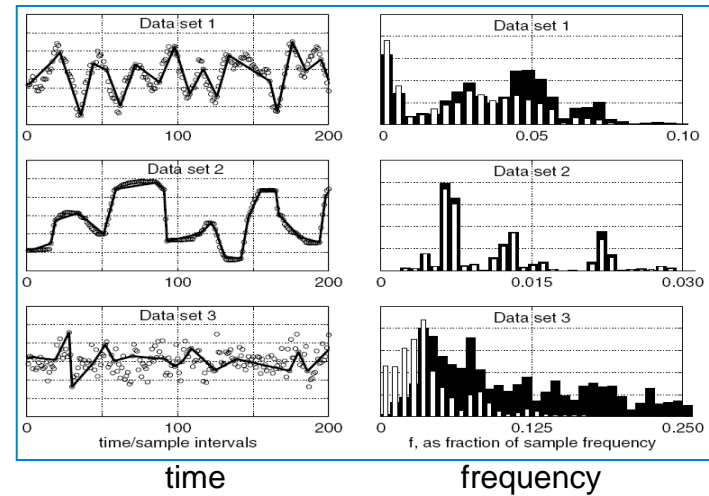
Process data analysis – Thornhill's way

- Root cause diagnosis
 - with Margret Bauer and Eastman Chemicals

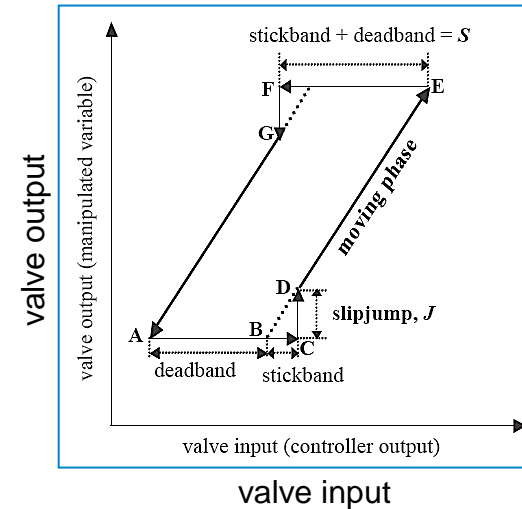


Process data analysis – Thornhill's way

- The effects of data compression
 - with Shoukat Choudhury

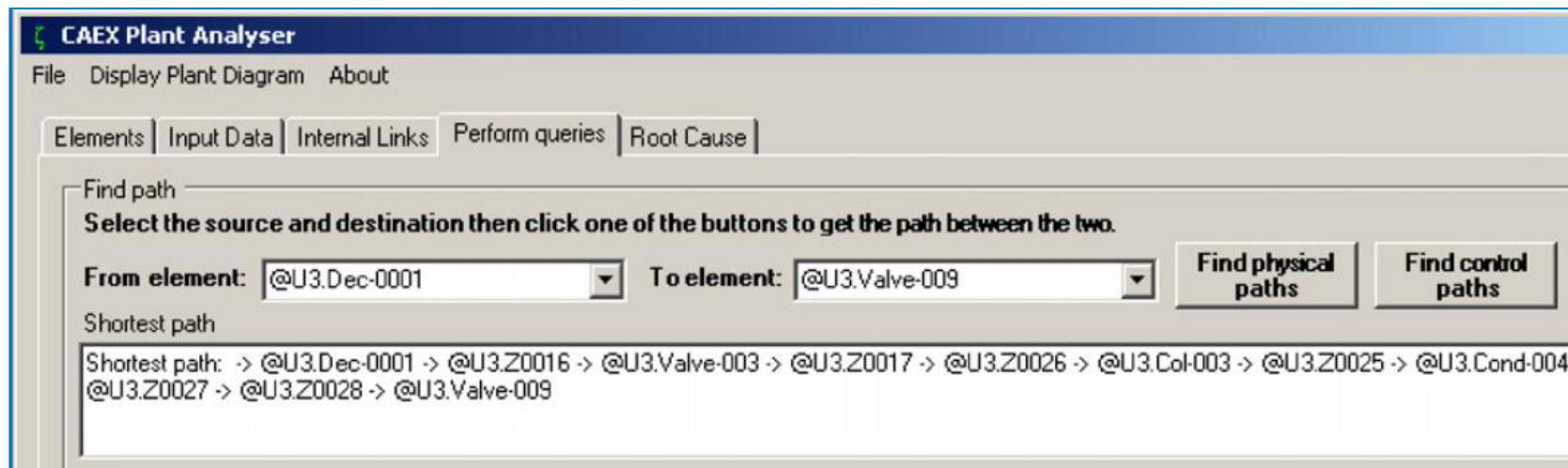


- Valve stiction analysis
 - with Shoukat and Sirish



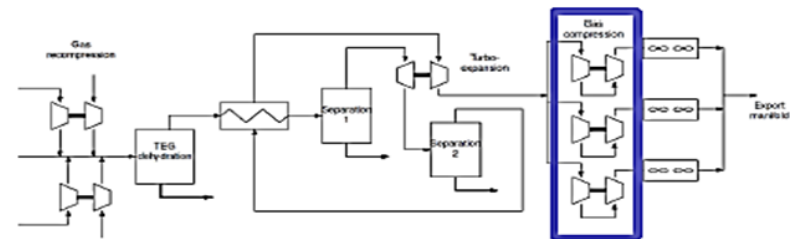
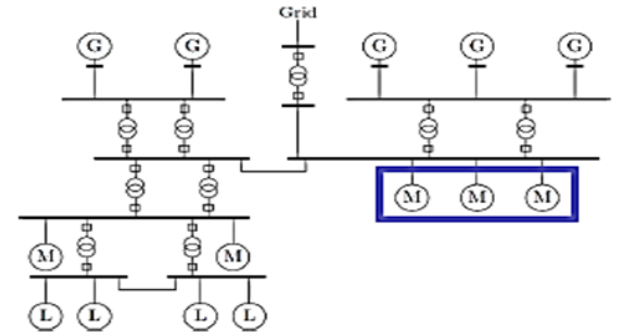
Process data analysis – Thornhill's way

- Linking data analysis with process topology
 - with Alexander Fay (HSU) and ABB

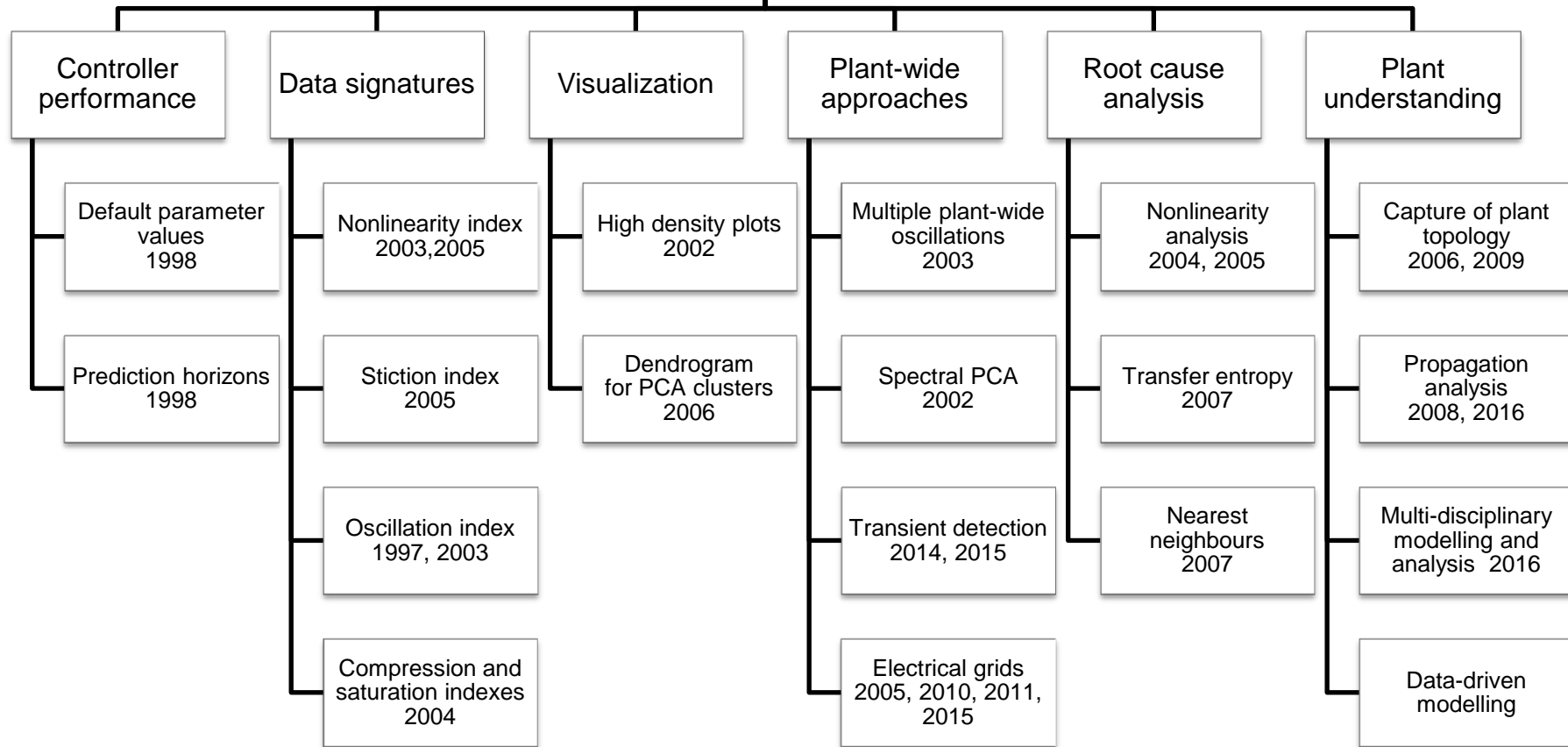


Process data analysis – Thornhill's way

- Industrial applications
 - Oil and gas, refining and chemicals with BP, Eastman Chemicals, ABB
 - Wide area power transmission grids with Statnett, Fingrid, and Bikash Pal of EE Eng Imperial
- Multidisciplinary disturbance detection and diagnosis
 - Electrical, mechanical, process and site utilities analysed together



What Thornhill and co-workers have done for ...



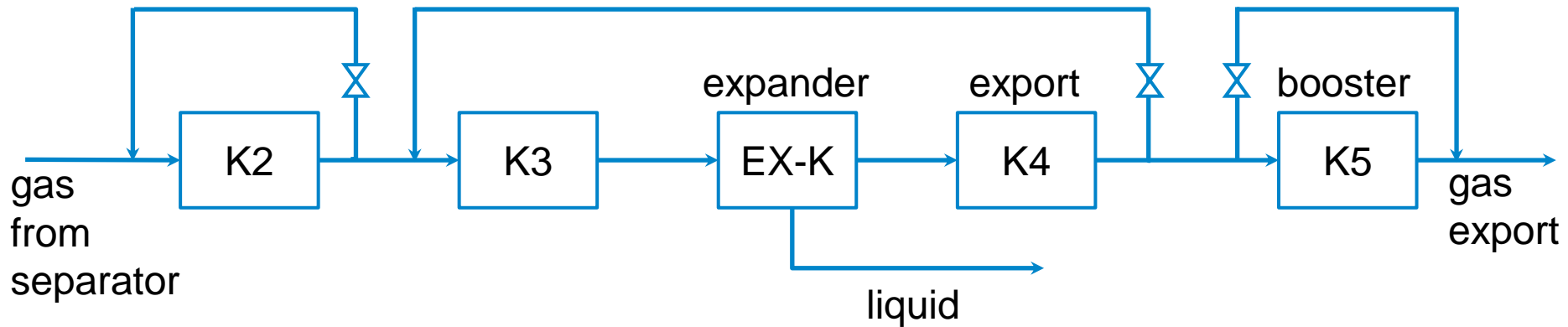
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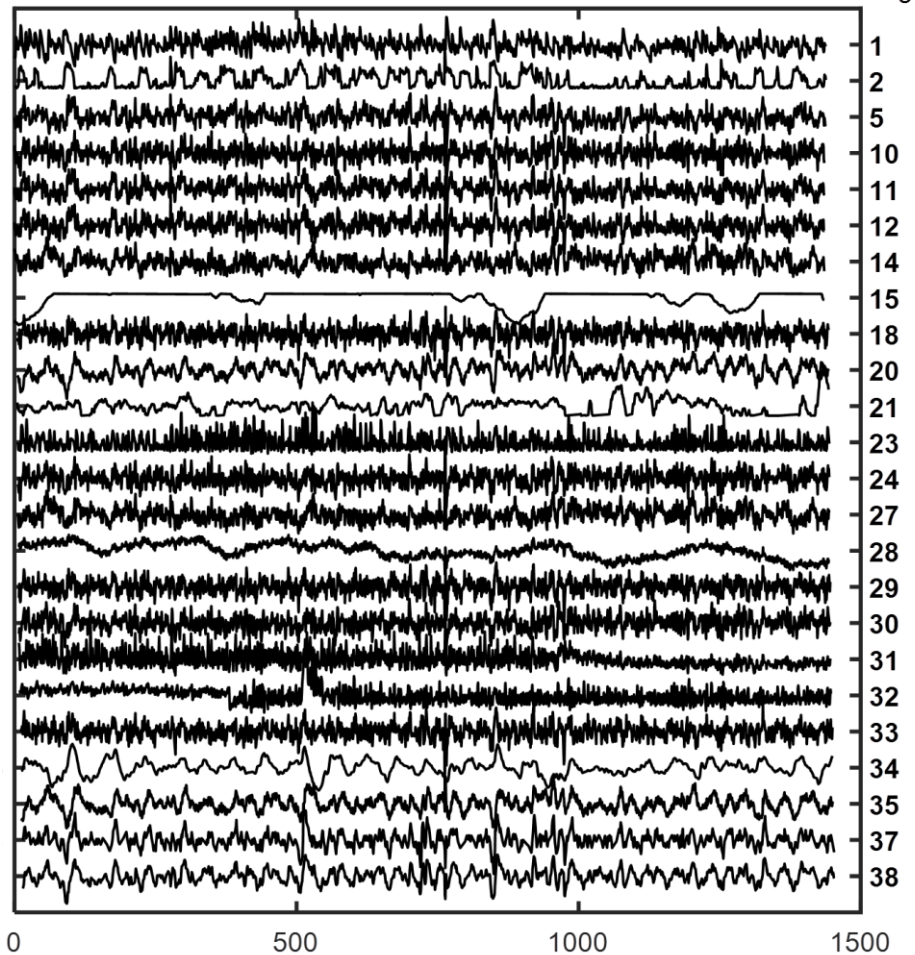
Plant-wide disturbances in an oil platform



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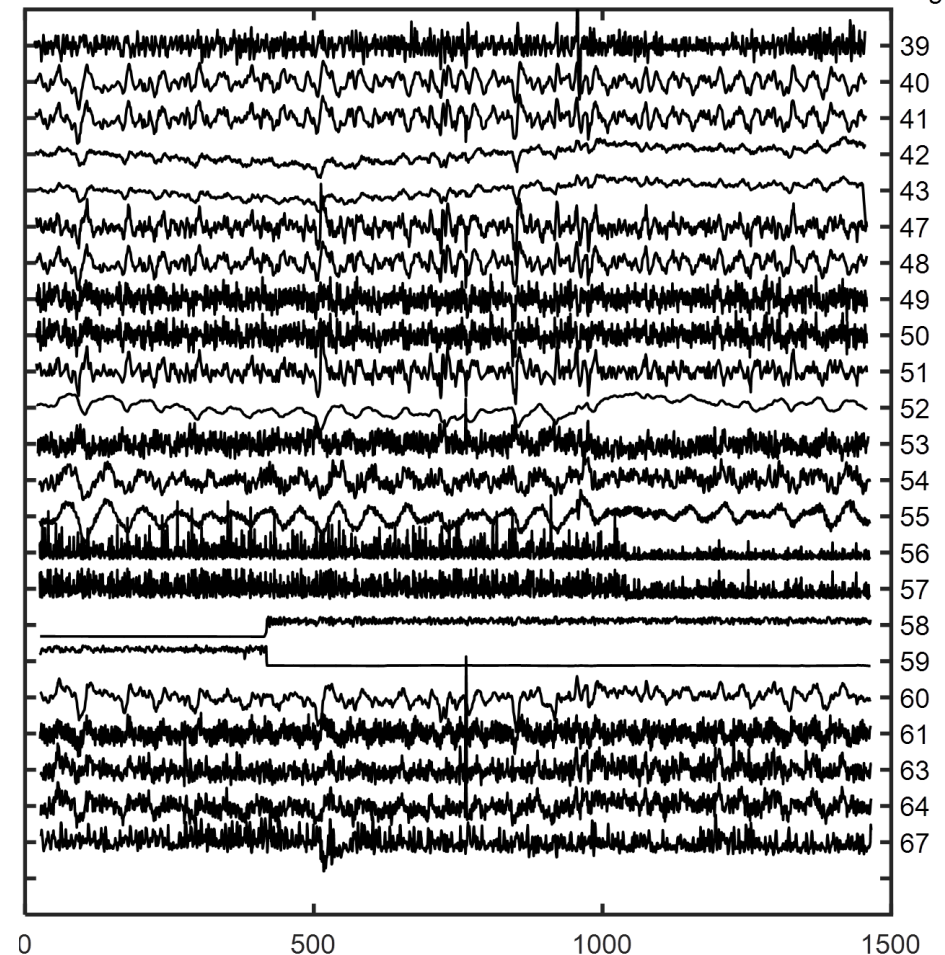


normalised trend



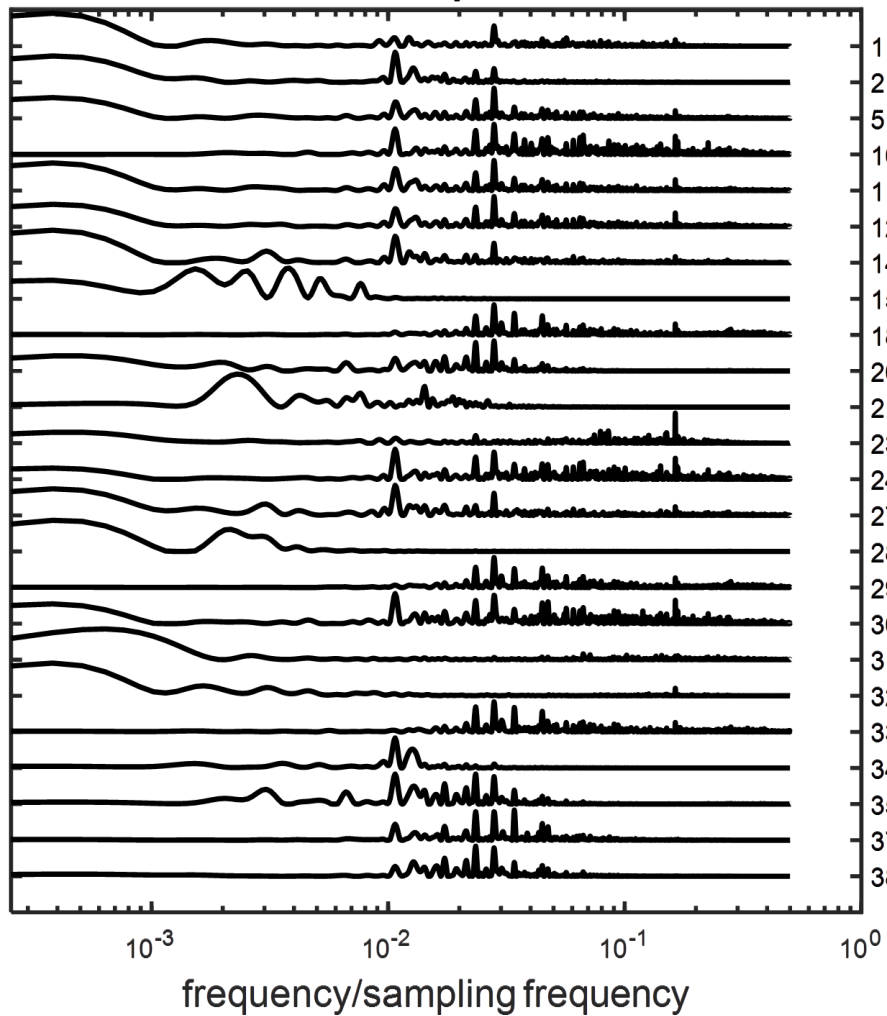
time/minutes

normalised trend

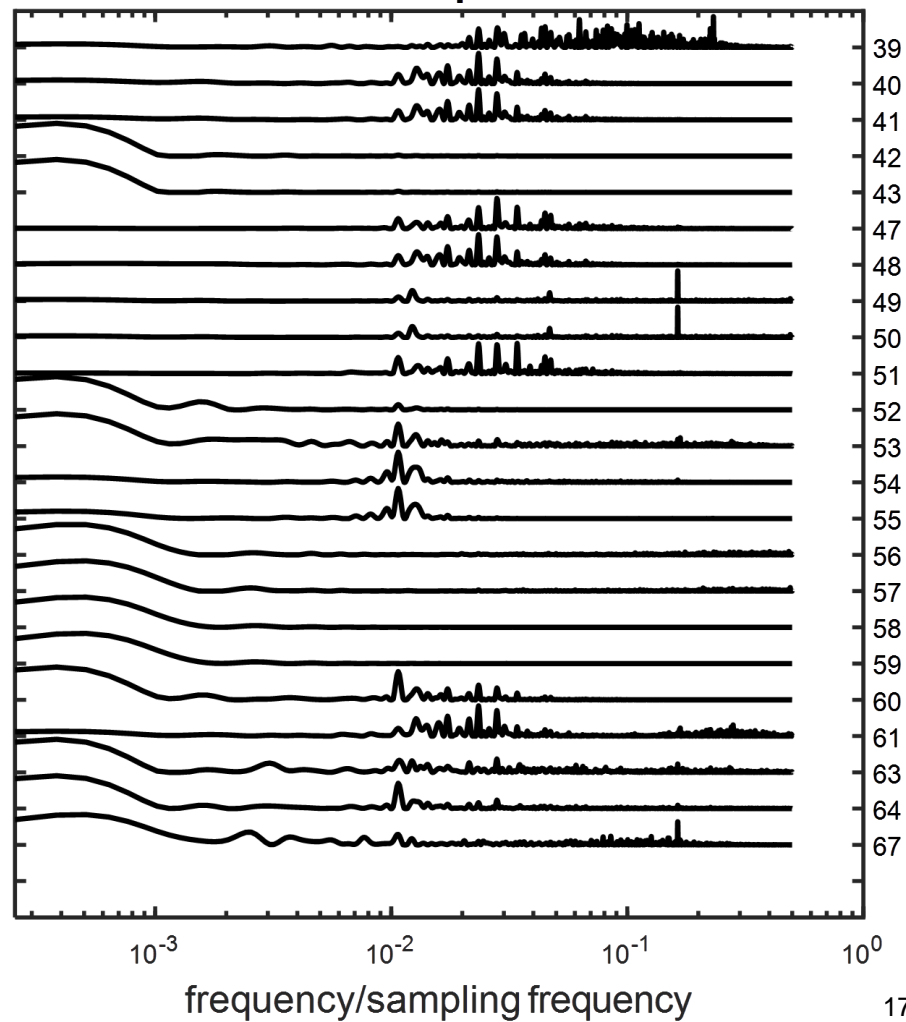


time/minutes

scaled spectra

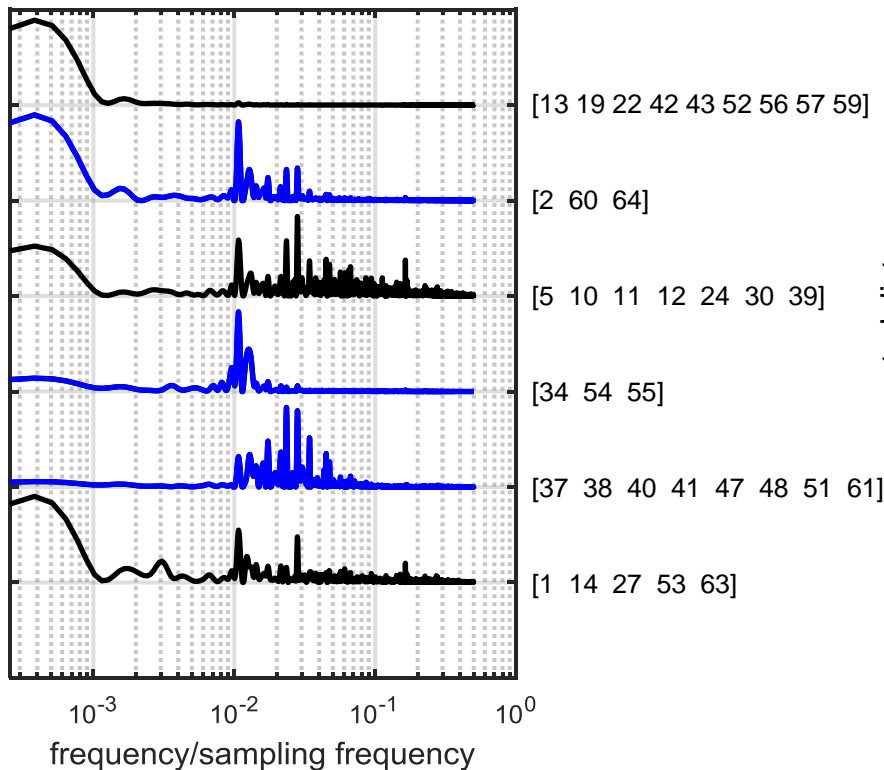


scaled spectra

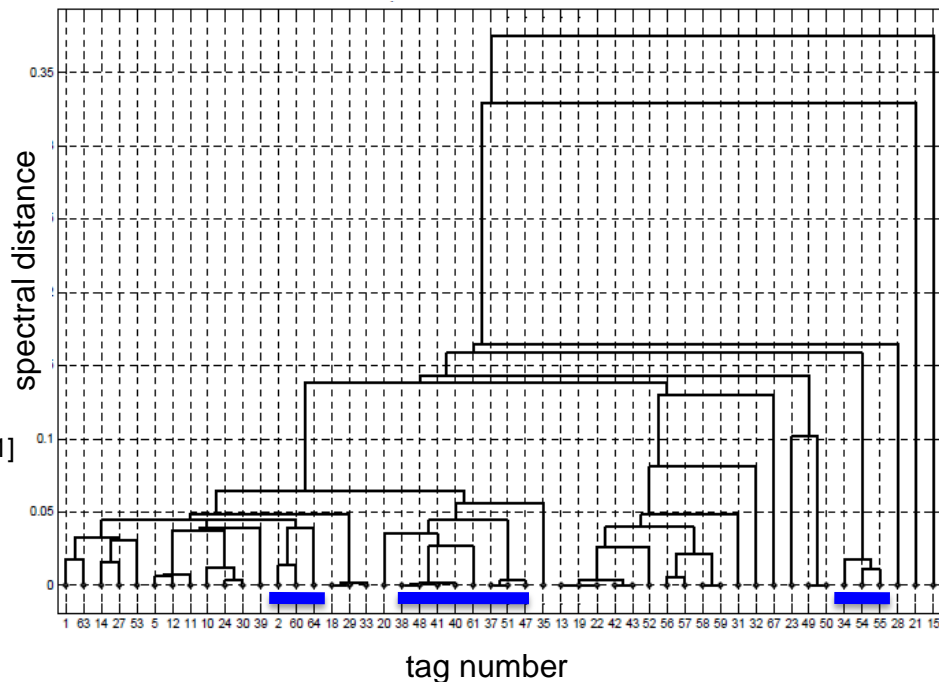


Plant-wide disturbances in an oil platform

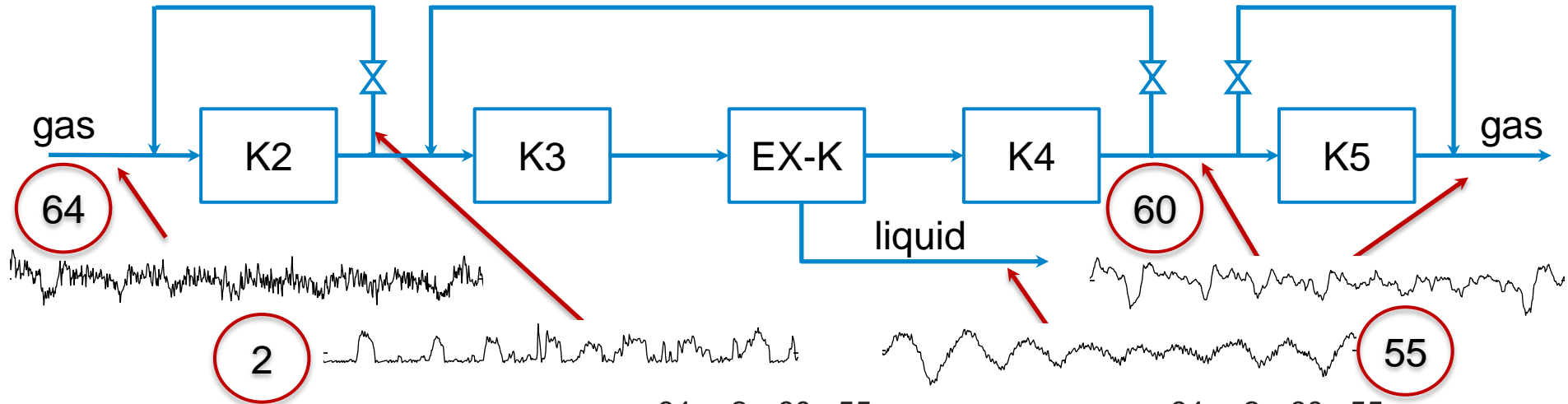
Spectral analysis shows
plant-wide disturbances



Spectral classification tree

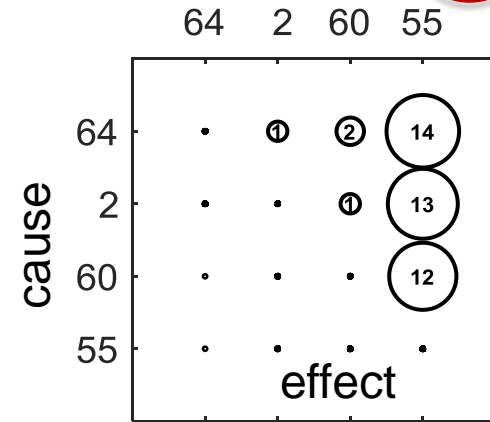
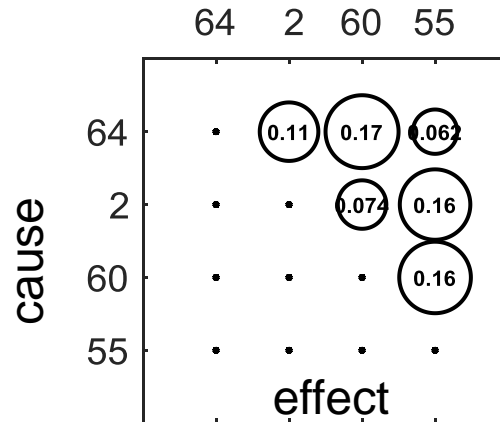


Plant-wide disturbances in an oil platform

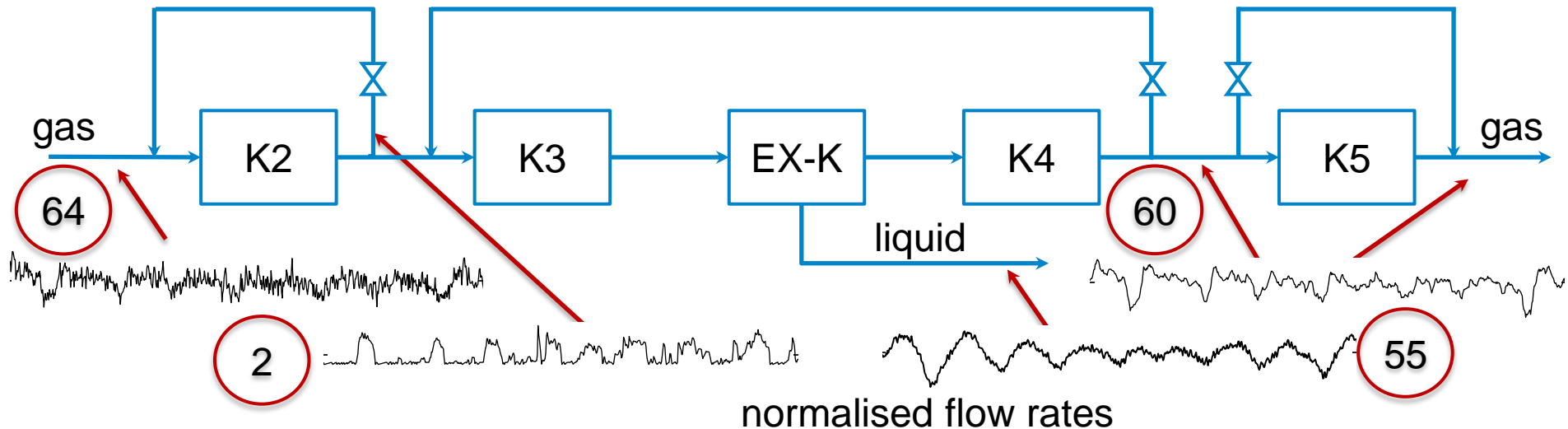


Flow rates

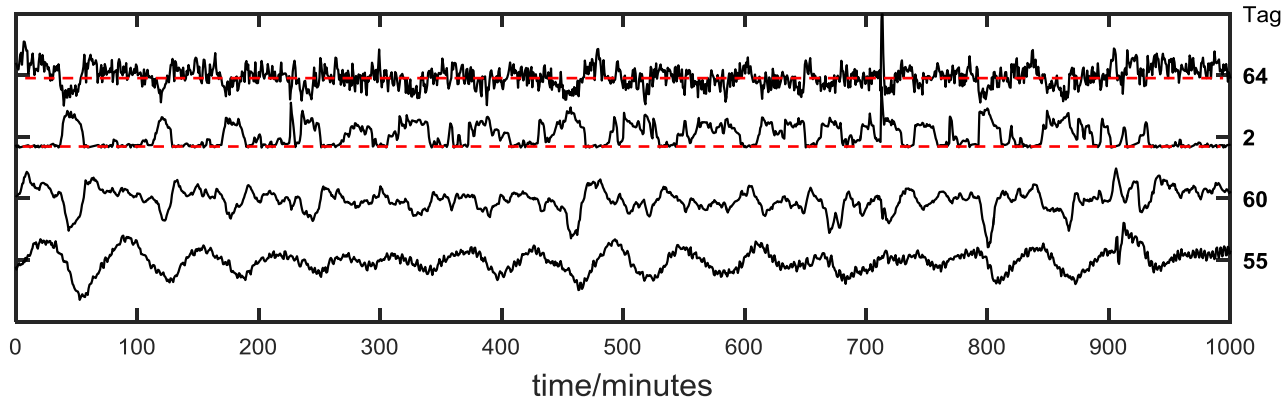
Root cause analysis using transfer entropy (left) and time delays/min (right)



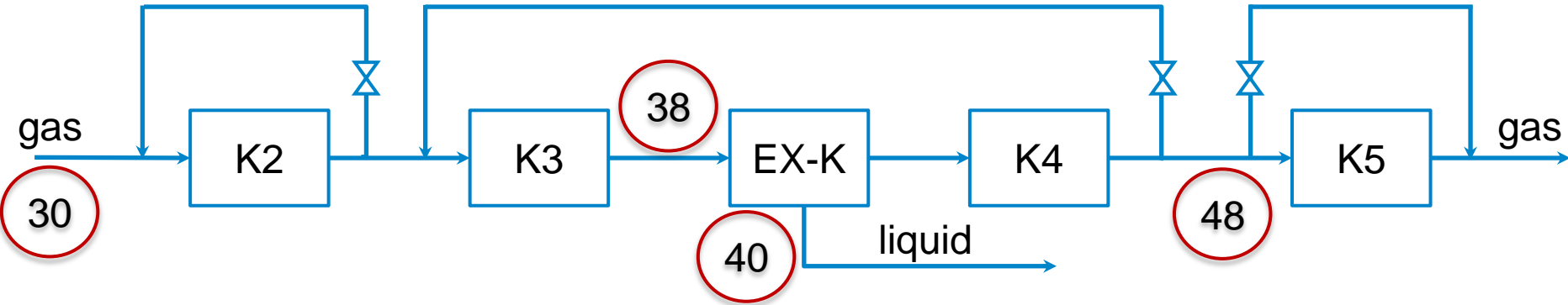
Plant-wide disturbances in an oil platform



Flow from separator
K2 recycle flow
K4 export flow
NGL flow

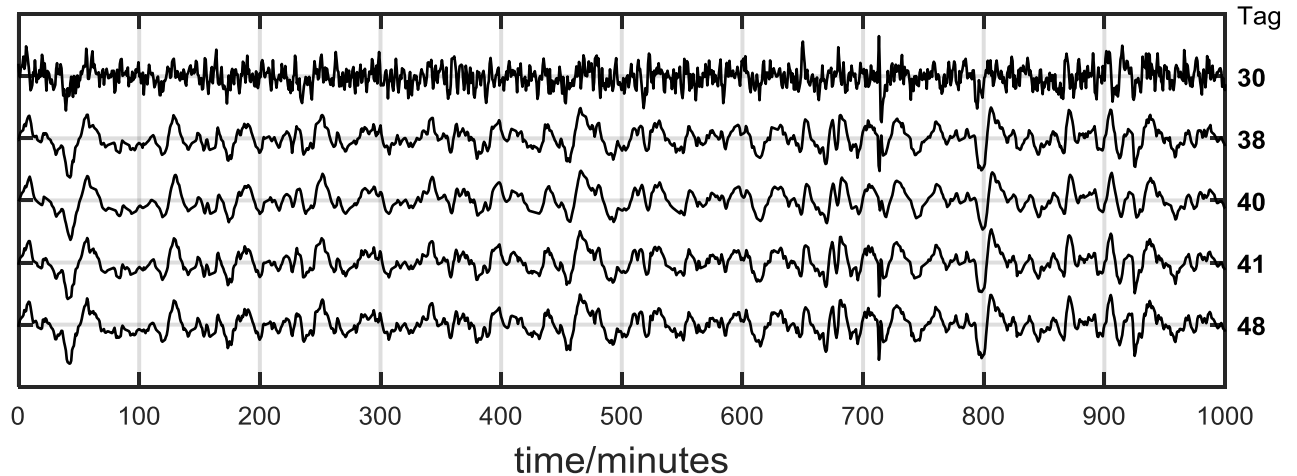


Plant-wide disturbances in an oil platform

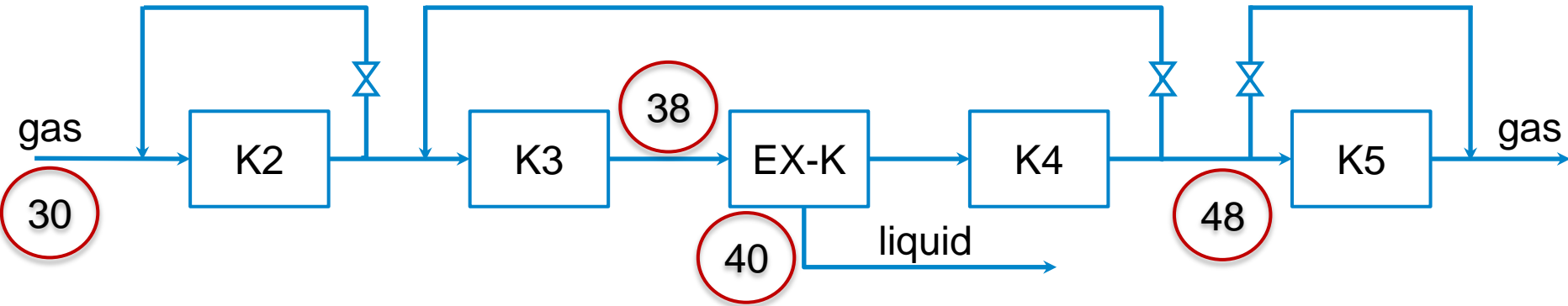


normalised pressures

Separator pressure
Various pressures
.
.
Final pressure

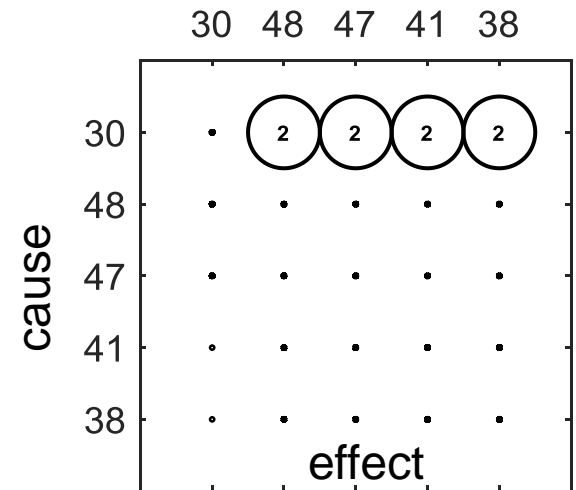
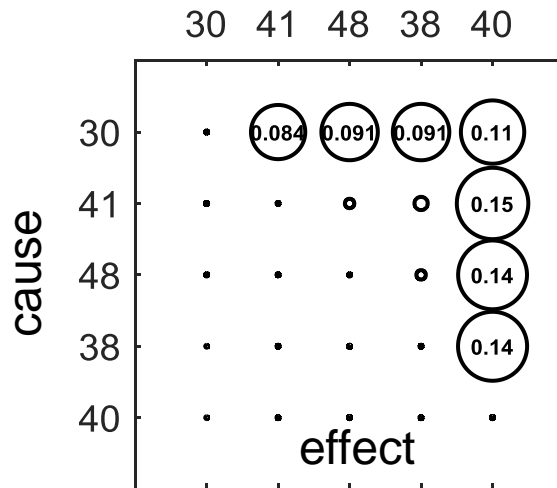


Plant-wide disturbances in an oil platform

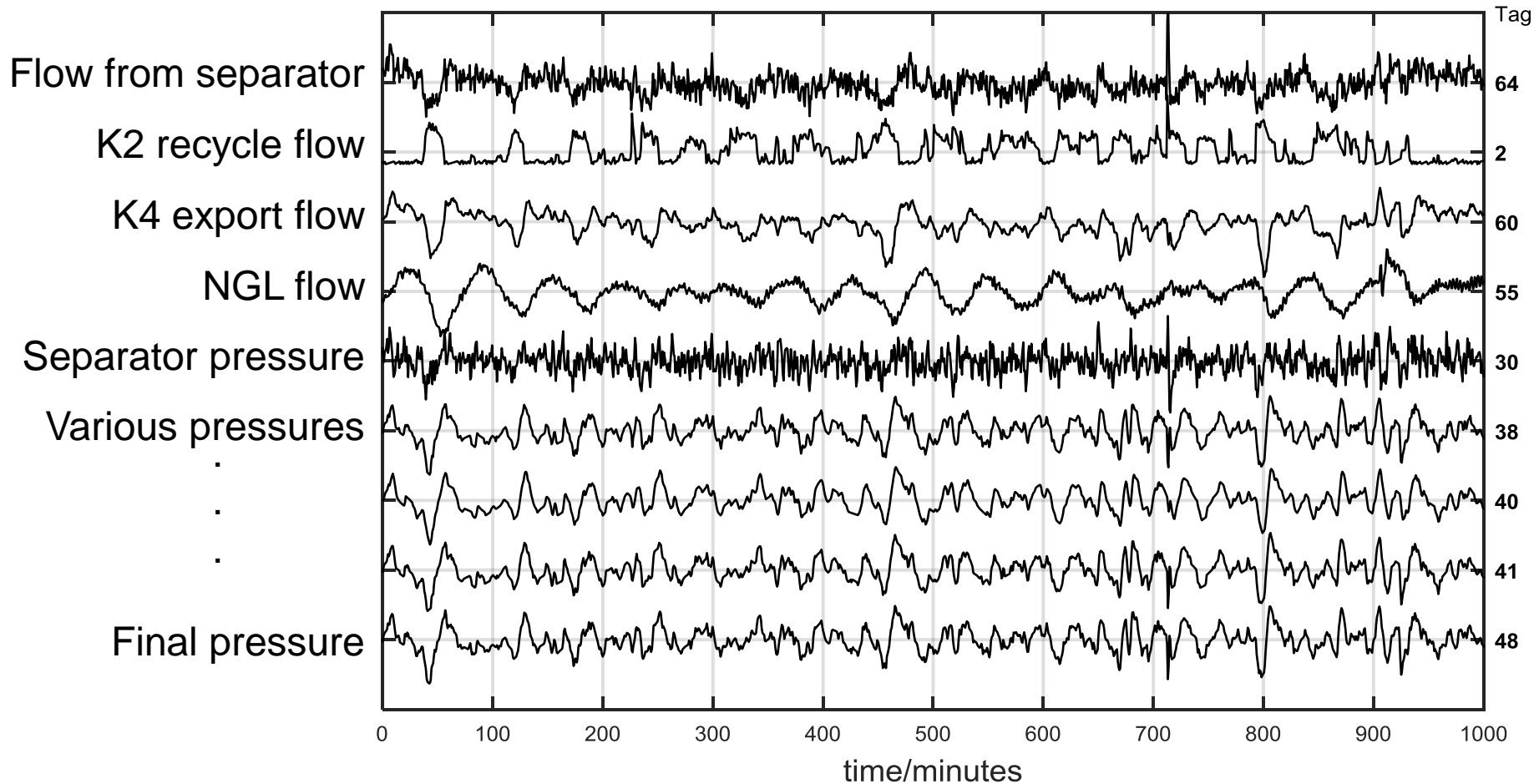


Pressures

Root cause analysis using transfer entropy (left) and time delays/min (right)

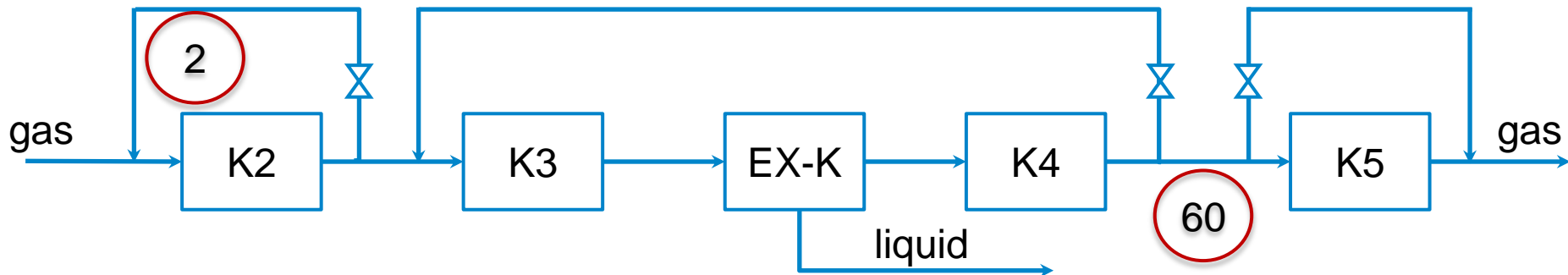


normalised trend

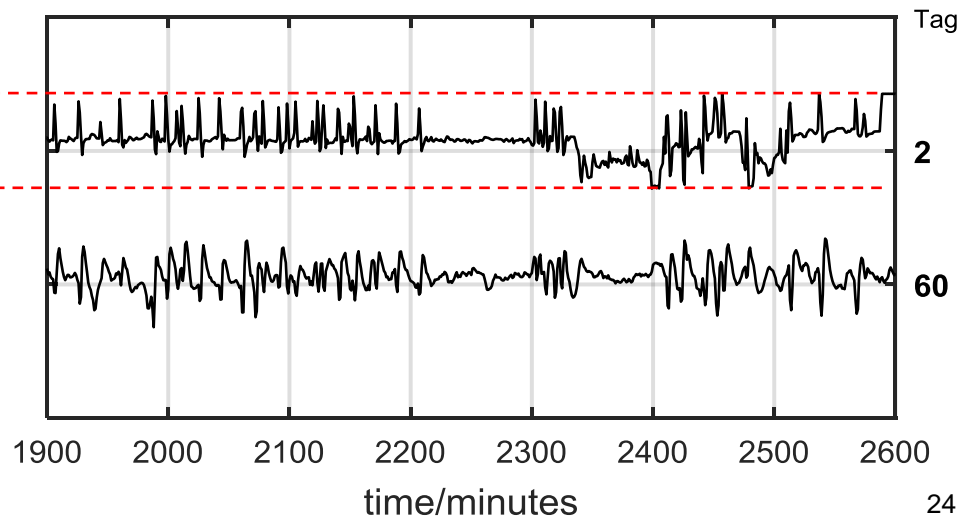
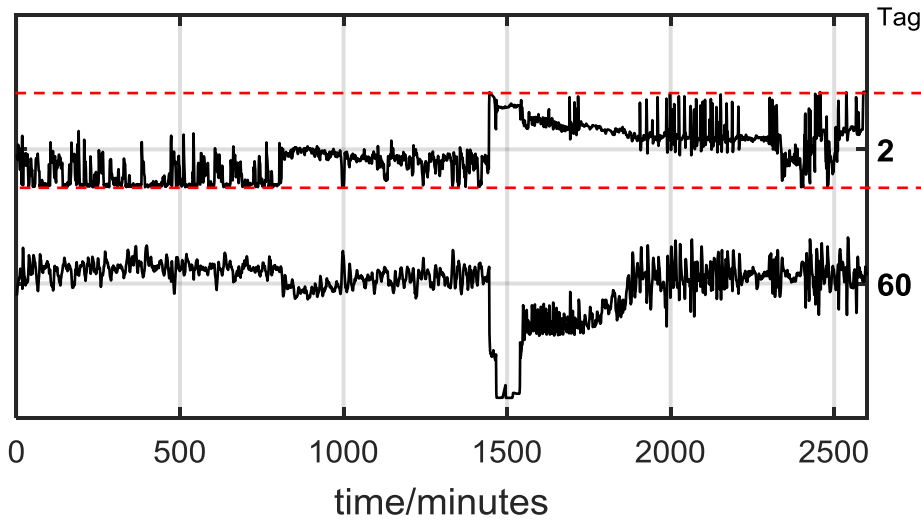


Low flow in (64) ⇒ compressor recycling (2) ⇒ pressure disturbances ⇒ amplified export flow disturbance (60)

Plant-wide disturbances in an oil platform



flow rates during a slugging incident two months later



Plant-wide disturbances in an oil platform

- Data analytics
 - Data compression detection
 - High density data plot
 - Saturation detection
 - Finding disturbance clusters
 - Root cause analysis
- Modelling
 - Data-driven models
 - e.g. compressor map from data
 - Structural models
 - e.g. “ a mass balance exists”
- Process insight and understanding
 - Understanding the process layout and operation
 - Generating hypotheses
 - Applying domain knowledge
 - Applying scientific training
- Manual steps
 - Finding the process configuration
 - Locating tags within the process

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Data analytics in autonomous operation

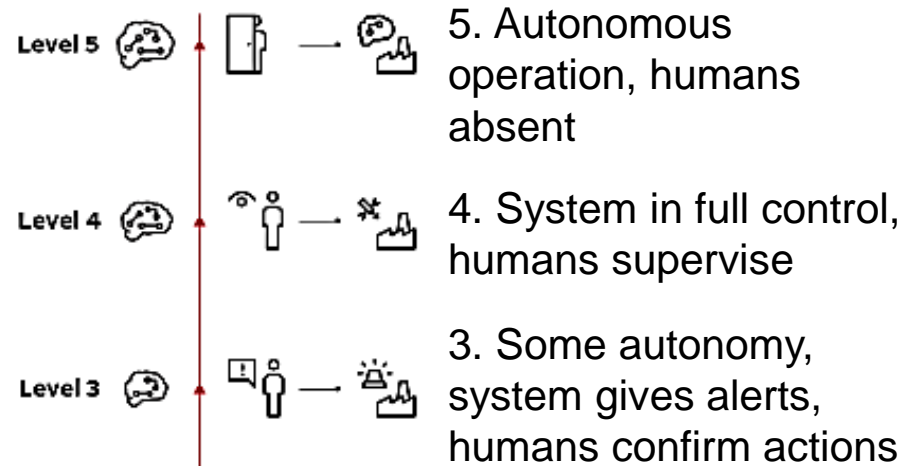
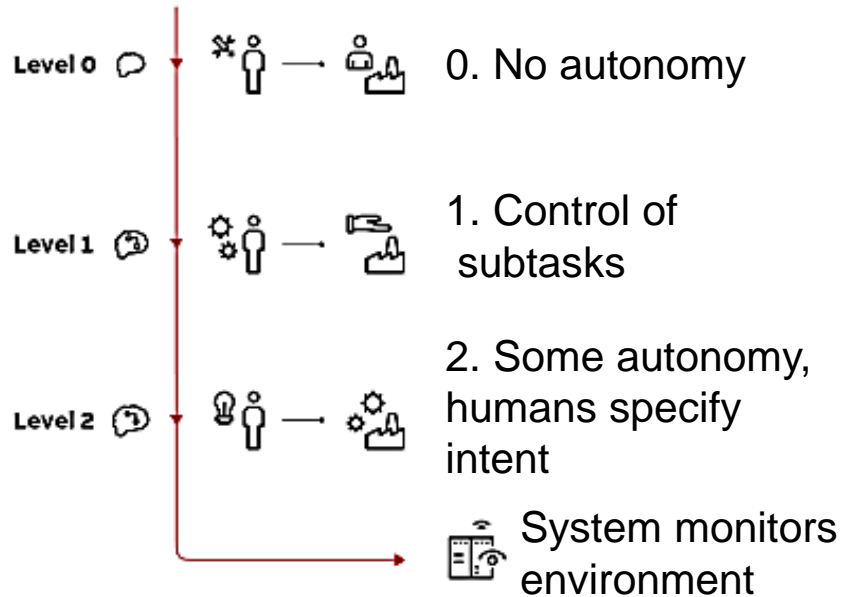
- Autonomous process operation

The Autonomous Industrial Plant – Future of Process Engineering, Operations and Maintenance

Thomas Gamer*, Mario Hoernicke*, Benjamin Kloepper*,
Reinhard Bauer*, Alf J. Isaksson**

*ABB AG, Corporate Research, Wallstadter Str 59, 68526 Ladenburg, Germany

**ABB AB, Corporate Research, SE-72178 Västerås, Sweden
(e-mail: alf.isaksson@se.abb.com)



Data analytics in autonomous operation

- Autonomous process operation is for:
 - Assisting humans
 - Taking over dull or difficult work
 - Replacing humans in dangerous work
 - Reducing human errors in using advanced technology
- Examples
 - ECA 400 PID controller (level 3)
 - oscillation detection in the background
 - Airplane autopilot (level 4)
 - autonomous operation within a pre-defined operating envelope

“Hero Russian pilot bestowed nation's highest medal for 'miracle' cornfield landing”

August 16th 2019



Data analytics in autonomous operation

- Mechanisms for achieving autonomy

Work done with James Ottewill and Trond Haugen, ABB

Control	Optimization	Data science	Machine learning	Artificial intelligence
Regulation to set point	Optimal set points	Insights	Predictions	Decisions and actions

Sources:

Business insider, 2015: “Here's the real reason artificial intelligence could be a threat”

www.businessinsider.com/autonomous-artificial-intelligence-is-the-real-threat-2015-9?IR=T

Artificial Intelligence, Robotics and ‘Autonomous’ Systems’, European Group on Ethics in Science and New Technologies 2018.
ec.europa.eu/research/ege/pdf/ege_ai_statement_2018.pdf

David Robinson

Chief Data Scientist at DataCamp, works in R and Python.



What's the difference between data science, machine learning, and artificial intelligence?

varianceexplained.org/r/ds-ml-ai/

Autonomy and Artificial Intelligence: A Threat or Savior? pub: Springer, 2017.
www.springer.com/gp/book/9783319597188

Data analytics in autonomous operation

- Mechanisms for achieving autonomy
 - Data science
 - produces insights
 - has a human in the loop to understanding the insight
 - Machine learning
 - produces predictions
 - has self-learning and algorithms that may not transparent
 - Artificial intelligence
 - produces actions
 - executes or recommends actions
 - Control and optimization
 - produces actions like AI
 - does not handle unexpected situations like an AI would

Data analytics in autonomous operation

- Data analytics

DS

- Data compression detection
- High density data plot
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- Root cause analysis

- Modelling

ML

- Data-driven models
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AI

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- Supervisors in our EU PRONTO project thought these are important:
 - Reaching high, being ambitious that you can change things
 - Looking at quality of the job and organization, not the specific topic
 - Understanding the motives of people whose support you need to realize your ideas
 - Promoting yourselves (Google scholar profile, ORCID number)
 - Having a road map for research
 - Always learning (it never stops)
 - Maintaining and using your networks
 - Understanding what you are doing, not “the computer said ...”
 - You are experts, do be confident, don’t be modest, but don’t be arrogant

Observations for younger generations

- I don't like working alone:
 - Long distances, no map
 - Difficult, lonely, risky
- I don't like doing incremental work:
 - Takes lots of effort and energy
 - One never really goes anywhere
 - It is crowded and competitive
- I don't like bandwagons:
 - “To the man with a hammer, everything looks like a nail”



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| Dreamstime.com



<https://www.bicycling.com>



Observations for younger generations

- I do like
 - Finding an interesting research path
 - Solving relevant industrial problems with appropriate techniques
 - Taking others with me

- So what *is* interesting?
 - ML and AI as mechanisms for delivering autonomy
 - Needs process data *and* models



“How can data tell you on the basis of no examples when the process will explode?”

(Sandro Macchietto, ESCAPE 2019)

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Acknowledgements

- Thank you to ...
 - All my collaborators and students
 - My funders, especially:
 - ABB Corporate Research
 - Royal Academy of Engineering
 - Royal Society and BP
 - FP7 and Horizon 2020
 - Engineering and Physical Sciences Research Council
 - My employers
 - Family and friends

END

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